AN ANALYSIS OF VARIATIONS IN BONE DENSITY
AND CORTICAL LOSS IN THREE NATIVE
AMERICAN SKELETAL POPULATIONS

by

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To Carolyn Nelson

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CHAPTER I

INTRODUCTION

It is clear that bone, as a dynamic organ, responds to changes in the body's physiological and structural requirements. Skeletal changes during growth, development, and aging represent adaptations to the changing needs of the individual throughout life. Although these changes are fairly regular and predictable, they are subject to stresses imposed by the environment. Inasmuch as individuals and populations are adapted to many different environments, there is some variation in the dynamics of age-related skeletal changes. These varying patterns in the gain and loss of cortical bone are the subject of much anthropological and medical research, and are the focus of the present study.

The phases of cortical gain and loss were outlined over a decade ago in a classic study by Stanley Garn (1970). Garn's study indicated that, in general, the loss of cortical bone after midadulthood seems to be inevitable in all populations. This generalization has been supported by subsequent medical and anthropological research (see Parfitt 1983 and Hummert 1983). However, there is a significant amount of variation in the timing and amount of bone loss in some individuals and populations; this variation has been associated with dietary factors, levels of physical activity, genetic constitution, and many diseases and metabolic disorders (Garn 1970; Perzigian 1973;

Ericksen 1976 and 1979; Thompson and Guiness-Hey 1981; and Ruff et al. 1984, for example). Recent anthropological research has focused on the relationship between some of the components of subsistence (i.e., diet and levels of physical activity) and patterns of cortical gain and loss (Mazess and Mather 1974; Ericksen 1976; Mensforth et al. 1978; Martin and Armelagos 1979; Richman et al. 1979; Cook 1979; Pfeiffer and King 1983; Bridges 1983; and Ruff et al. 1984, for example).

The present study examines intra- and interpopulation variation in bone loss with advancing age in three skeletal populations with different subsistence bases. It is suggested that the interpopulation variation in bone loss is related to the differences in subsistence, specifically diet. Several hypotheses are proposed which concern the relationship between age and sex factors, diet, and the pattern of bone loss in the three populations. These hypotheses provide a framework for understanding the differences and similarities between populations, both past and present, in their patterns of cortical gain and loss.

Anthropologists have traditionally been interested in the processes which bring about human differences and similarities (Harris 1971). The perspective with which they approach this investigation has been characterized as "multi-disciplinary, comparative, and diachronic" (Harris 1971: 6). That is, anthropologists compare the biological, biocultural, and cultural adaptations of populations in different environmental and chronological contexts. The research problem that is central to the present study is of anthropological interest in that it concerns variation within and between three populations that represent different adaptive strategies. The purpose of the study is to clarify the role of dietary factors in the patterning of cortical gain and loss in the populations.

Although much anthropological and medical research has been concerned with the identification of contributory factors in the gain and loss of cortical bone, the present study is novel in two respects. First, it examines the relationship between dietary differences and the variation observed in patterns of cortical gain and loss among three skeletal populations. Hypotheses predicting the relationship between subsistence and bone loss are proposed and tested. Second, a new index of bone density, which is described and utilized in the analysis, provides insight into the dynamics of bone loss in the study populations. Its potential use for future research on cortical gain and loss is clear.

Statement of the Problem

Studies of past populations have indicated that hunter-gatherers differ from maize agriculturalists in their patterns of cortical gain and loss (Stout 1978; Cook 1979; Pfeiffer and King 1981; and Ruff et al. 1984). Specifically, many maize agriculturalists in eastern North America appear to have suffered chronic nutritional stress and exhibit a significant bone deficit (see Buikstra and Cook 1980). Cook (1979) suggests that it is the transition to maize agriculture which is associated with stress. Manifestations of this stress include deficient bone growth and consolidation, and excessive age-related bone loss (see Buikstra and Cook 1980).

Although many causal factors have been implicated in this phenomenon, dietary variables and levels of physical activity have received the most attention in anthropological reasearch. A review of the literature indicates that the role of dietary factors in bone loss is better understood than is the effect of activity differences in populations. Therefore, in the present study, it is suggested that the population differences in cortical loss are associated with differences in diet, although the potential effects of activity differences are considered.

There are many dietary factors which may contribute to a reduced bone mass among periodic maize agriculturalists. These include a high phosphorus/low calcium ratio in the diet; periods of low food intake; protein-calorie malnutrition; post-weaning dietary stress and its synergism with disease; and Vitamin C, zinc, and iron deficiencies (Gilbert 1975; Mensforth et al. 1978; Stout 1978; Cook 1979; Richman et al. 1979; Buikstra and Cook 1980; and Pfeiffer and King 1983). These chronic problems have not been reported for prehistoric hunter-gatherers. Therefore, it is expected that the maize agriculturalists in the present study exhibit a bone deficit throughout adulthood, and lose more bone after midadulthood, when compared with hunter-gatherers.

In addition to the study of variation between populations, intra-population (age and sex) variation will be examined. Based on Garn's (1970) findings and those of other recent studies, it is predicted that bone loss after midadulthood is apparent in each population. However, it is expected that females lose more bone than do males. The amount of bone lost after midadulthood may be related to events affecting the growing skeleton and, by implication, bone mass among young adults. This relationship seems to apply to the populations included in the present study.

Method of Analysis

In order to test the hypotheses proposed in Chapter IV, samples of cortical bone were obtained from the femora of adults in three skeletal populations. These populations are from the Black Earth site, Illinois; Dickson Mounds (Larson Phase), Illinois; and Fletcher, Michigan. Hunting-gathering characterized the Black Earth population, while the Dickson Mounds and Fletcher samples represent agriculturalists. The archaeology and physical anthropology of the sites are described in Chapter III.

Although the hypotheses were formulated before the data were collected, and appropriate methods of analysis were determined, it was impossible to obtain large enough sample sizes for some of the preferred statistical tests. While the Black Earth sample is large (46 males and 38 females), the sizes of the Fletcher and Dickson Mounds samples were limited by unforeseen circumstances. Officials of the Illinois State Museum system approved the removal of cortical samples from a maximum of 30 individuals in the Dickson Mounds collection. The Fletcher sample consists of at least 93 individuals, but because of the poor condition of many of the specimens, only seven adult males and 14 adult females were included in the data collection. Of these, only the females were analyzed.

Because of these limitations on the sample sizes of two of the three sites, some alterations in the choice of analytical methods were necessary. Specifically, t-tests have been replaced with Fisher's Exact tests and more descriptive analytical tools (such as percentage differences in the means) for the Dickson Mounds and Fletcher data. These analyses are discussed in detail in Chapter VI, Results.

The cortical samples consist of rectangular pieces of the femoral cortex which were cut out of each specimen with an emery saw attached to a high-speed craft drill. The samples were easily removed with both the subperiosteal (outer) and endosteal (inner) surfaces intact. The bone mineral content and cortical thickness of each sample were obtained, as well as whole-bone measurements and other data from the skeleton.

Photon absorptiometry was employed to estimate the bone mineral content of each specimen. Cortical thickness was measured directly on each specimen with calipers. Other measurements included maximum morphological length of the femur and circumference at the site of sample removal. Several indices were generated from these data, and are described in Chapter V.

In summary, the present study examines variation within and between three skeletal populations in adult cortical gain and loss. The relevant medical and anthropological literature is examined, and hypotheses predicting patterns of variation are generated. It is suggested that differences between the populations in regard to cortical loss after midadulthood are associated with differences in subsistence. The relationship between dietary factors and skeletal changes, especially with advancing age, will be emphasized.

CHAPTER II

BACKGROUND TO THE PROBLEM

Introduction

The skeleton is a dynamic organ that responds to the changing needs of the individual throughout life. Its many fucntions include the protection and support of the soft tissue, and the storage and provision of essential minerals and other elements (Rogers 1982). The unique properties of bone, with its two-phase mineral and organic composition, allow it to perform these vital functions.

Because of their unique structure and hardness, bones grow through a specialized mechanism (Enlow 1968). Skeletal growth and development require that bone be capable of both enlargement and remodeling in order to maintain the proper proportions of the growing bone (Enlow 1968). These processes involve a combination of resorption from and deposition on both surfaces of a bone, depending on the direction of any given change. That is, bone is deposited on bone surfaces which face the direction of change, and bone is generally resorbed on the opposite surface (Enlow 1968: 58). Bones are also remodeled internally, throughout a lifetime, by the same processes of resorption and deposition.

In general, skeletal growth and development proceed in a fairly regular and predictable pattern (McKern and Stewart 1957; Garn 1970; and Krogman 1962). The loss of bone with advancing age is also predictable in that it is apparently part of the aging process (Garn 1970; Parfitt 1983). Despite these regularities, the gain and loss of cortical bone throughout the life of an individual are affected by many factors, some of which are specific to the individual or to a population. Therefore, there are both intra- and inter-population variations in the patterns of skeletal changes (Garn 1970 and 1972). These variations, especially with regard to bone loss, are the focus of the present study.

Skeletal Growth and Maintenance

It is clear that an understanding of bone dynamics is essential to the study of age-related bone loss. Skeletal development begins in a non-mineral cartilage and membrane phase in the fetus. This anlage is gradually replaced by boney spicules, beginning in the first trimester of embryonic development (Burdi et al. 1976). Bone growth continues, by a combination of apposition and resorption, throughout childhood and early adulthood, ceasing when growth centers have fused.

Bone remodeling occurs throughout life in response to continuous biomechanical and physiological needs (Vaughan 1981). For example, older necrotic bone is continually replaced by new, more vascular bone (Enlow 1976). Also, bone may be deposited or resorbed in response to biomechanical stress (Enlow 1976).

A significant role of the skeleton is to provide a reservoir of minerals for the body's metabolic needs (Vaughan 1981). The mineral phase of bone consists mainly of calcium and phosphorus, in a specific ratio that is only slightly variable (McLean and Urist 1968). Other constituents include carbonate and citric acid; and small amounts of elements such as sodium and magnesium and various trace elements (McLean and Urist 1968). The maintenance of the skeleton reflects the delicate balance that exists between the structural requirements of the skeleton and the metabolic requirements of other organs with respect to these bone minerals.

The quantity of mineralized bone is influenced by mechanisms of mineral homeostasis and bone turnover (Lampmann et al. 1984). Apparently, in older individuals, the dynamics of mineral regulation change and begin to degrade, resulting in bone loss without significant replacement (Ortner 1976). Ortner suggests that the decline in mineralization with age may be related both to the capacity of the osteocytes (bone cells) to mediate mineralization and to the diminished quality of the osteoid (protein matrix) to be mineralized (Ortner 1976: 38). The result is a reduction in bone turnover and in mineralization of the protein matrix in bone with advancing age (Ortner 1976).

Bone Loss After Midadulthood

One trend that is universal in human skeletal biology is the loss of cortical bone after midadulthood (Garn 1970 and Parfitt 1983). Until about age 35 or 40, there is a net gain and a consolidation of cortical bone mass that results from apposition at the endosteal (inner) and subperiosteal (outer) surfaces of long bones (Garn 1970 and Parfitt 1983). After that period, age-related bone loss occurs as a result of apparent degenerative changes in the body's ability to regulate mineral homeostasis (Ortner 1976).

The phases of change in cortical bone throughout life were first described in a classic study by Stanley Garn (1970). From radiographs of diverse, contemporary populations, Garn found that, in general, apposition of bone at the subperiosteal surface of long bones continues throughout life. According to Garn (1970), bony changes at the endosteal surface occur in three phases, as follows:

1. resorption from birth through adolescence as bones grow in length and width;
2. deposition from adolescence until midadulthood as growth slows;
3. resorption after midadulthood (about 40 years) as cortical loss begins.

While these patterns are universal, rates of cortical gain and loss, which determine the gross amount of cortical bone, differ among individuals and populations (Garn 1970 and 1972).

These differences are of interest to anthropologists, who have studied the phenomenon of cortical loss in past and in extant populations (Dewey et al. 1969; Armelagos et al. 1972; Perzigian 1973; VanGerven 1973; Mazess and Mather 1974 and 1975; Carlson et al. 1976; Ericksen 1976 and 1979; Richman et al. 1979; Martin and Armelagos 1979; Thompson and Guiness-Hey 1981; Mazess and Christiansen 1982; and Pfeiffer and King 1983). In general, these studies have supported Garn's findings with respect to patterns of variation in cortical loss. Three generalizations can be drawn from these studies, as follows:

1. In all populations, individuals lose cortical bone after midadulthood.
2. In all populations, females lose more bone after midadulthood than do males.
3. Different populations exhibit different patterns in the gain and loss of cortical bone.

These generalizations provide the framework for the hypotheses that are proposed in Chapter IV of the present study.

Bone loss after midadulthood is believed to be affected by nutritional deficiencies or excesses, levels of physical activity, hormonal changes, and various pathological conditions (Guyton 1976; Thompson and Guiness-Hey 1981; Parfitt 1983; Brewer et al. 1983, for example). Therefore, systematic differences between populations with regard to these factors may account for the observed variation in cortical loss patterns. Researchers have also implicated genetic factors in population differences in cortical gain and loss (see Ericksen 1976), and it is clear that patterns are different for males and females (Garn 1970).

The quantity of bone mass among older individuals is probably influenced by events that affected the growing skeleton (Parfitt 1983). For example, individuals or populations that have greater bone mass in young adulthood are less likely to suffer significant bone loss in older age (Garn 1981).

A reduction in bone mass is considered to be significant, in a clinical sense, when it results in a fracture (Parfitt 1983). One form of bone loss which increases one's risk of fractures is known conventionally as osteoporosis (Parfitt 1983). Specifically, osteoporosis is characterized by a deficiency in the quantity, but not in the quality, of bone (Lampmann et al. 1984).

In summary, the loss of cortical bone after midadulthood is universal and, in most cases, can be considered a normal developmental phenomenon (Rogers 1982; Parfitt 1983). Sometimes, however, the reduction in bone mass is extreme and increases an individual's fracture risk. The amount of cortical loss not only varies on an individual basis, but patterns of cortical loss also differ between populations. This variation is influenced by genetic and environmental factors.

Because this variation in cortical bone loss may reflect differences in adaptation in human populations, it is of anthropological interest. As was discussed in Chapter I, anthropological research is generally concerned with a comparison of the ways in which human populations respond, or adapt, to the environment. With respect to the present study, variation in cortical bone loss is examined in relation to subsistence, which is a major component of a population's adaptive strategy. The present study contrasts three skeletal populations that represent two different subsistence regimes, hunting-gathering and agriculture. Specifically, it is suggested that differences between the populations with regard to cortical loss are related to the differences in subsistence.

It is clear that subsistence strategies are complex systems with numerous and variable components which include technological and dietary factors, and which involve different levels of physical activity. The two variables which are considered in the present study are levels of physical activity and diet, as these factors are known to affect the gain and loss of cortical bone (Parfitt 1983). The dietary factors in cortical gain and loss will be emphasized, as they are currently better understood than are the relative contributions of differences in physical activity.

Physical Activity

Medical research has indicated that inactivity contributes to bone loss (Brewer et al. 1983). Conversely, physical activity helps to prevent, and even reverse, bone loss (Smith 1974; Brewer et al. 1983). It is clear that physical activity levels, as components of subsistence activities, must be considered as part of the present study on cortical loss. However, as will be discussed, a review of the recent anthropological literature concerning subsistence, physical activity, and skeletal changes reveals no consistent pattern.

A recent study of skeletal material by Ruff et al. (1984) considers the structural changes in the femur which presumably resulted from the transition to agriculture in a prehistoric Native American population from the Georgia coast. The study examines cross-sectional geometric properties which, according to the authors, reflect mechanical functions. These were chosen to help distinguish between dietary and mechanical factors in skeletal structure. The conclusions emphasize that the structural differences between the agricultural and hunting-gathering groups represent a redistribution of bone that is best explained by changes in mechanical requirements. This redistribution includes "localized remodeling or shape changes in the skeleton" (Ruff et al. 1984: 135). Nutritional changes, according to the authors, would be reflected in changes in overall body size. They suggest that ". . . it is unlikely that a nutritional change (short of an obvious gross pathology such as rickets) would explain the redistribution of bone area within cross-sections that was observed" (Ruff et al. 1984: 131-132). They conclude that the agricultural group from the Georgia coast experienced a decrease in mechanical stress in the femur compared with the earlier hunting-gathering group. They also note a decrease in stature in the agriculture group.

Their model is weakened somewhat by a similar comparison with a second agricultural group, from Pecos Pueblo, New Mexico (Ruff et al. 1984). Pecos Pueblo is similar to the agricultural Georgia coast population in that both were dependent on corn agriculture at about the same time period (1300-1600 A.D.), albeit in different environments. The results of this comparison suggest that for most of the structural properties of the femur, the Pecos Pueblo sample resembles the preagricultural sample more than it resembles the agricultural sample from the Georgia coast. However, two "shape" indices (reflecting adaptations to "bending loads in the antetorsional plane of the femoral head and neck") are similar in the two agricultural samples (Ruff et al. 1984: 134). From these data the authors conclude that while the agricultural groups experienced different levels of physical activity, they engaged in similar types of activities. These activities include "less running and climbing, and more walking and possibly other more sedentary pursuits such as lifting and carrying" (Ruff et al. 1984: 134). With respect to body size, the authors note that the Pecos femora are shorter than either Georgia coast sample. Yet, the Pecos femora are at least as strong and robust as those from the hunting-gathering sample from the Georgia coast, but much more so than those of the Georgia agriculturalists (Ruff et al. 1984). This conflicting information clearly does not strengthen the authors' model, which attempted to distinguish between mechanical and nutritional stresses. That is, it is not clear from this study that physical activity requirements are reflected in the cross-sectional structure and remodeling of bone, while nutritional levels are reflected by body size or shape.

In another recent study of the relationship between subsistence and the biomechanical properties of bone, Bridges (1983) examined bone strength in femora and humeri from northwest Alabama. These data were obtained with a C-T (computerized tomography) scanner in five cross-sections of the diaphyses. Bridges concluded that bending and torsional strengths increased in the Mississippian (agricultural) group over the Archaic hunter-gatherers, especially among females. Her conclusions contrast with those of Ruff et al. (1984) in that she observed an increase in mechanical requirements in the agricultural group while Ruff et al. inferred from their data a decrease in strenuous activity and an increase in more sedentary pursuits.

It appears that one of the problems with studies of "physical activity" is that of quantifying the level of activity under consideration relative to other activity levels. While Ruff et al.

(1984) consider lifting and carrying to be "sedentary pursuits," Bridges considers the tasks of low-technology agriculture to be more demanding, physically, than hunting-gathering (Bridges, personal communication).

The problems associated with classifying levels of activity are further exemplified in the model provided by a 1973 FAO/WHO report on Energy and Protein Requirements (FAO/WHO 1973). This report identifies four levels of physical activity, which are "light," "moderate," "very" and "exceptionally" active. These cattegories correspond to daily energy expenditures in terms of kilocalories. In this report, agriculture is considered to be either moderate or very active work (FAO/WHO 1973).

In a recent study of extant horticulturalists, Defour (1984) found that the daily energy expenditure reported for seven different populations ranged from light activity to exceptionally active. That is, based on energy expenditure, the horticulturalists could be placed into all four categoires of physical activity.

These studies illustrate an apparent inability to characterize agriculturalists as more or less physically active than other populations (i.e., hunter-gatherers). Therefore, there is no apparent basis for assuming that either the hunter-gatherers or the agriculturalists in the present study were more or less physically active than the other. In the absence of evidence to the contrary, especially with respect to the femur, it cannot be assumed that the levels of physical activity are significantly different in the two subsistence groups. It is clear that walking, which affects the femur, is one activity that continues to be a prevalent part of the daily activity in the transition to agriculture (Dufour 1984 and Ruff et al. 1984).

It must be acknowledged, however, that a recent study by Bridges (personal communication) indicates that the transition to agriculture in a southeastern U.S. population had a dramatic effect on arm strength, especially in females. This increase in arm strength is consistent with the method of grinding corn described for historic southeastern Indian cultures. This, however, is irrelevant to changes in the femur, which are the focus of the present study.

Dietary Factors

While the differences in the levels of physical activity in hunter-gatherers and agriculturalists are unclear, nutritional differences are better understood. The introduction of maize as an important part of the diet in prehistoric eastern North America had several important effects upon nutrition. In general, it seems to have resulted in increased nutritional stress (Gilbert 1975; Buikstra and Cook 1980). Specifically, maize is relatively low in protein and calcium, but high in its phosphorus content (Gilbert 1975; Pfeiffer and King 1983). It also contains chelating agents which inhibit the body's absorption of some essential elements, such as zinc and iron (Gilbert 1975; Mensforth et al. 1978).

The effects of these dietary characteristics, in conjunction with the effects of increased sedentism and population density, are reflected in indicators of health among maize agriculturalists. For example, infectious disease is more prevalent among maize agriculturalists (Mensforth et al. 1978; Buikstra and Cook 1980). The use of corn gruel as a weaning food is associated with anemia in infants, which interacts synergistically with disease (Scrimshaw 1964; Mensforth et al. 1978; Buikstra and Cook 1980). Some research on maize agriculturalists has suggested that protein-calorie malnutrition accounts for many of the indicators of stress observed in skeletal populations (see Buikstra and Cook 1980). Dietary stress also affects the gain and loss of cortical bone which, as the focus of the present study, will be examined in more detail.

As was discussed earlier, diets which have a high content of meat protein may effect a high rate of bone mineral loss (Wachman and Bernstein 1968; Mazess and Mather 1974; Richman et al. 1979; see also Nutrition Reviews 1981). There are two mechanisms which may account for this effect. First, the body's need to neutralize the high acid ash content of meat may result in the removal of minerals from bony reservoirs (Wachman and Bernstein 1968). Second, although high meat diets are generally high in phosphorus, the accompanying dietary intake of calcium may be low. If the ratio of phosphorus to calcium is too high, then PTH (parathyroid hormone) synthesis may be stimulated in order to release calcium from the bones. The obvious result is that bone resorption occurs (Mazess and Mather 1974; Jowsey 1978; Pfeiffer and King 1983; see also Nutrition Reviews 1981).

These effects of a high-meat diet are relevant to Eskimo and to contemporary U.S. populations. However, a diet in which corn is a staple food may also have the high phosphorus/low calcium effect on bone mineral homeostasis, especially during growth and development. In a recent study, Pfeiffer and King (1983) obtained low values for measures of cortical bone formation among two protohistoric Iroquoian populations. By current standards, these indicated a high incidence of osteoporosis in the groups (Pfeiffer and King 1983).

Similar results are reported in a study of west-central Illinois populations representing the shift to maize agriculture (Stout 1978). Stout found increased bone turnover rates among the agriculturalists which he attributes to the calcium-deficient diet that was based on corn. Cook (1979) found thinned cortices in these same populations (Buikstra and Cook 1980).

It has also been suggested that bone loss may occur in response to periodic starvation or low food intake (Richman et al. 1979). According to Richman et al. (1979), starvation can cause an excess of ketone bodies in the blood, which stimulates the removal of bone mineral to act as a buffer. Periods of low food intake, during which levels of serum calcium decline, may also cause the removal of calcium from bone (Richman et al. 1979).

It is probable that the periodic agriculturalists in the present study experienced periods of low food intake and a high phosphorus/low calcium diet. This proposition is inferred from the cumulative evidence of other research on maize agriculturalists (see Buikstra and Cook 1980). This research tends to "reinforce a notion of dietary stress attendant upon maize cultivation in eastern North America" (Buikstra and Cook 1980: 453).

Although this model of dietary stress seems to apply to many early maize agriculturalists in the eastern U.S., it is not necessarily applicable to all early agriculturalists in the U.S. For example, two independent studies which compared bone loss among Eskimo, Arikara, and Pueblo populations indicate that the Pueblo exhibit less bone loss with advancing age than do either of the other two groups (Ericksen 1976 and Richman et al. 1979). The Pueblo (Colorado) were sedentary agriculturalists with a vegetarian diet; the Arikara (South Dakota) supplemented horticultural production with hunting; and the Alaskan Eskimo were largely carnivorous (Richman et al. 1979). Ericksen (1976) found that femoral cortical loss among the Pueblo after middle age was less than in the other groups of the same sex. These results are supported by another study of the same groups. Richman et al. (1979) found that the Pueblo exhibit less intracortical remodeling than the other two groups. The type of remodeling they studied may be related to the exchange of minerals that is required for physiological homeostasis (Richman et al. 1979).

One generalization which may be drawn from the anthropological research discussed in this section is that populations which are partially dependent on maize exhibit more bone loss than do either preagriculturalists (see Buikstra and Cook 1980) or vegetarians (such as the Pueblo: Ericksen 1976; and Richman et al. 1979). These generalizations provide the framework for the hypotheses about interpopulation variations in the present study. That is, these hypotheses state that the patterns of cortical gain and loss in one hunting-gathering population (from Black Earth) are significantly different from those observed in two agricultural populations (from Dickson Mounds and Fletcher). Furthermore, it is expected that the hunter-gatherers from Black Earth will exhibit less cortical loss than will the maize agriculturalists.

Medical research concerning the relationship between diet and bone loss is consistent with much of the anthropological research. It also suggests that some relationshps are not well-defined. A recent article by A. M. Parfitt (1983) reviews the relationship between dietary factors, age-related bone loss, and fractures. He summarizes the effects on bone mass of dietary calcium, phosphate, protein, calories, sodium, fluoride, ascorbic acid, and trace elements, as well as Vitamin D production. He concludes that "for many nutrients, both very low and very high intakes are harmful to bone, but variation in between has little effect" (Parfitt 1983: 1184). The one exception is dietary calcium, since relatively small variations can significantly affect the bone mass. This is especially important during the periods of growth and consolidation; that is, before midadulthood (Parfitt 1983). Dietary calcium also apparently affects the rate of bone loss after midadulthood (Parfitt 1983).

The mechanism that causes bone loss when calcium intake is low is the secretion of parathyroid hormone and the production of calcitriol, or Vitamin D (Parfitt 1983). The former causes the release of calcium from bone as well as renal conservation of calcium. Calcitriol governs the absorption of calcium in the gut (Parfitt 1983). These mechanisms constitute an individual's adaptation to low calcium intake that deteriorates with age and that "varies considerably between individuals and between populations" (Parfitt 1983: 1181). According to Parfitt, it is not clear whether population differences reflect evolutionary or individual adaptations.

The long-term effect on bone mass of variations in dietary phosphate is also unclear (Parfitt 1983). In nonhuman animals, high levels of phosphate cause cortical loss because they induce secondary hyperparathyroidism. However, "sustained hyperparathyroidism" has not been observed among humans, and studies of the relationship between bone mass and phosphate intake in humans have not been done (Parfitt 1983). Apparently, the conclusions of anthropologists about the effect on human bone loss of high dietary phosphorus are inferred from studies of nonhumans.

One conclusion which can be drawn from Parfitt's review is that dietary factors affect the growing skeleton. One inference which can be made is that these effects will be reflected in the adult skeleton. The probability that adult bone mass depends on calcium intake throughout life has already been mentioned. It has also been demonstrated by medical and anthropological researchers that protein-calorie malnutrition in childhood results in growth retardation and thin cortices (Buikstra and Cook 1980; Garn 1970; Himes et al. 1975; Parfitt 1983; Hummert 1983). The result is that "bone mass is low relative to age," and it is not known "whether these losses are recoverable" (Parfitt 1983: 1183). Presumably, if the protein-calorie deficiency is chronic (that is, not reversed), recovery would be impossible. This situation may apply to some prehistoric maize agriculturalists who were apparently under "chronic nutritional stress" (Martin and Armelagos 1979; Buikstra and Cook 1980).

Other dietary factors which may affect growth and, presumably, adult bone mass, are certain trace elements. Zinc, for example, is necessary for normal growth and development of the skeleton (Parfitt 1983). It is interesting to note that in Gilbert's study of the Dickson Mounds material, he found that zinc may be a determinant of adult stature (Gilbert 1975). Zinc is one of the elements which, despite its presence in a diet based on maize, may be unavailable for metabolism (see Gilbert 1975). Although zinc is present in most grains, it is bound by phytates that are also present. The resultant chemical complex is insoluble and nonabsorbable (Oberleas et al. 1966).

One final relationship between diet and bone mass will be noted. Parfitt (1983) reports that in a study of young Bantu males, fractures related to osteoporosis were associated with a deficiency of ascorbic acid (Vitamin C). In prehistoric populations from Illinois, Cook (1979) suggests that there is some evidence for scurvy (Vitamin C deficiency) in children. She inferred this from the association between periostitis and cortical bone loss in the sub-adult skeletons. Thus, diets which are deficient in ascorbic acid may adversely affect the growing skeleton and, by implication, adult bone mass.

In summary, it is clear that dietary variations influence patterns of cortical gain and loss. It has been demonstrated that calcium, phosphorus, protein, calories, zinc, and ascorbic acid affect skeletal growth and/or adult bone mass. The anthropological literature indicates that maize agriculturalists were subject to growth retardation, a higher incidence of disease, reduced bone mass, and significant age-related bone loss. Medical research supports, in general, the proposition that a diet based on corn, and subject to periodic or chronic deficiencies, adversely affects the skeleton.

Summary

This chapter provides a review of skeletal growth and development and the dynamics involved in adult bone loss. The relative contributions to changes in bone mass of variables related to physical activity and diet are also reviewed. Generalizations and conclusions drawn from medical and anthropological research provide the basis for the hypotheses proposed in the present study. The hypotheses predict specific patterns of variation in bone loss within and between three skeletal populations.

It is suggested that differences in subsistence, especially in dietary factors, are related to differences between populations in the gain and loss of cortical bone. In the present study, hunter-gatherers are contrasted with maize agriculturalists. For the reasons discussed in this chapter, it is expected that the agriculturalists gain less bone in early adulthood and lose more bone after midadulthood than do the hunter-gatherers.

CHAPTER III

DESCRIPTION OF SITES

Introduction

Three Native American skeletal populations were sampled for this study. One large site, Black Earth, represents a hunting-gathering population. Two smaller samples were obtained from the Dickson Mounds (Larson Phase) and Fletcher sites, which represent agricultural populations. These sites were chosen for comparison because of their contrasting subsistence bases and because they are well-documented archaeologically.

Each site is described below. Archaeologically-derived models of ecology and subsistence will be discussed, dates established, and the nature of the skeletal sample described.

The Black Earth Site: Hunting and Gathering

The Black Earth site is located in the Carrier Mills Archaeological District in southern Illinois (Figure 1). It is situated in an area of environmental diversity that includes the rolling hills of the Till Plains, dissected by stream valleys and bottomland forest, and the more rugged Shawnee Hills (Lopinot and Lynch, n.d.). The site itself is on a low upland area near the Saline River and adjacent to the remnants of a Pleistocene lake which has recently been drained (Jefferies 1980). The surrounding microenvironments offered a wide

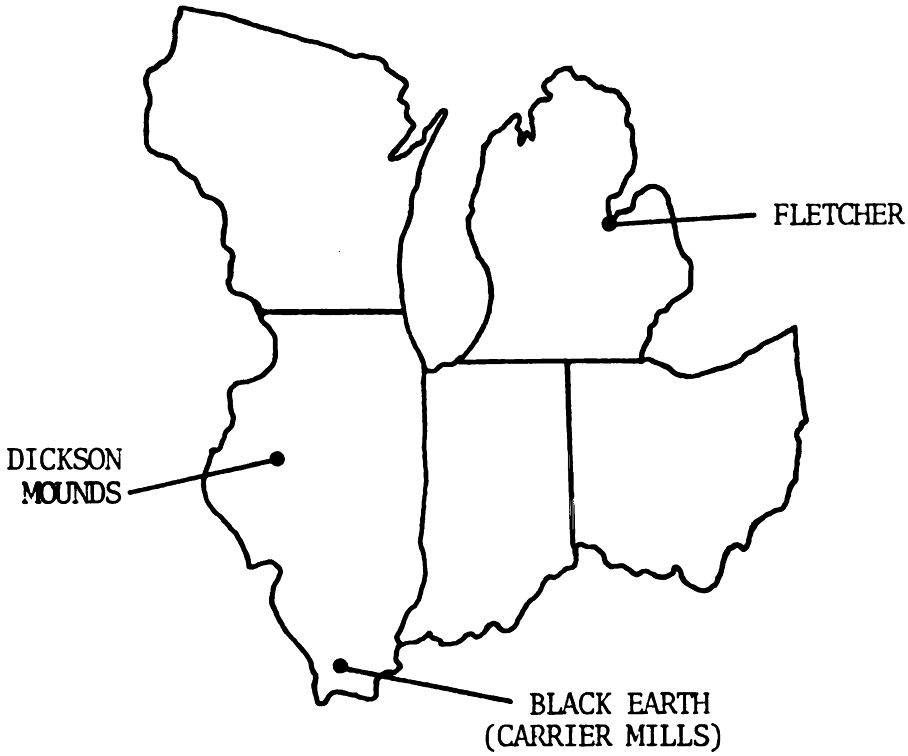

Figure 1.--Geographic locations of sites.

range of food resources for its early inhabitants, including aquatic fauna and a rich supply of game and plant resources (Jefferies 1980 and Lopinot and Lynch n.d.). Based on the availability of these rich and varied resources, a model of year-round habitation and exploitation of the Shawnee Hills and Till Plains by late Middle Archaic and Woodland populations has been generated for the Black Earth site. This model is supported by botanical, faunal and archaeological data (Jefferies 1979; Jefferies and Butler 1982; and Lopinot and Lynch, n.d.).

To date, faunal and floral evidence has indicated continuity through time in the settlement-subsistence pattern of prehistoric populations at the Black Earth site. For both late Middle Archaic and Woodland populations, white-tailed deer and, to a lesser extent, turkey were the most important terrestrial vertebrates exploited, while turtles, aquatic birds, and small mammals were also utilized (Breitburg 1980). The computation of dietary rations for the Black Earth site midden and features suggests that the site's inhabitants procured approximately the same amount of meat from the same species throughout the 5500 years of cultural deposits contained at the site (Breitburg 1980).

The botanical remains recovered from the site also demonstrate much continuity from the late Middle Archaic through the Woodland periods. For example, nut collection, especially hickory and acorn, was important during both periods. Evidence from the Carrier Mills Archaeological District suggests a slight increase by Middle Woodland times in the use of such seed plants as Chenopods and Maygrass

(Lopinot, personal communication). Evidence for maize and squash agriculture during the Middle and Late Woodland periods is scant and/or unreliable (Lopinot and Lynch n.d.).

In summary, the subsistence model which emerges from these data is one of generalized hunting and gathering during the Archaic and Woodland periods, with an increasing emphasis on native seed plants. This is consistent with other current models of subsistence in the riverine areas of the Midwest (Griffin 1978; Muller 1978; Fitting 1978; Asch, Ford and Asch 1972). These studies indicate that seeds had become important dietary items by the Middle Archaic and were utilized intensively and selectively by the Middle Woodland period.

The Black Earth site yielded the remains of over 200 individuals, most of which were in excellent condition (Jefferies 1982). Of these, 84 adults were analyzed for the present study, and it is assumed that they constitute a representative sample. These were specimens which were sufficiently complete for age and sex determination, and for identification of the bony landmark from which the cortical samples were taken.

Another criterion for inclusion in this analysis was a specimen's assignment to either the Archaic or Woodland component. There was some difficulty in determining the cultural affiliation of many of the burials (Jefferies 1982). Burials often were not associated with temporally diagnostic artifacts; and other dating methods, such as the measurement of the nitrogen content in bone, did not yield definitive results (Jefferies 1982). However, burials were finally assigned to one of the two components on the basis of their points of origin below surface. This classification scheme was based on two radiocarbon dates and on the presence of diagnostic artifacts with some of the burials (Jefferies 1982). Some burials of uncertain cultural affiliation, especially in the middle levels, were left unclassified.

The radiocarbon dates indicate that the earliest activity at the Black Earth site occurred in approximately 3955 B.C. (Jefferies 1982). According to Jefferies, the Archaic period burials represent a period of at least 1000-1500 years, and the Woodland period lasted up to 2000 years at the Black Earth site.

Physical anthropological research at the Black Earth site includes a comprehensive osteological analysis (Bassett 1982) and mortuary analysis (Lynch 1982). Specific studies of stress indicators (Larsen 1981), non-metric traits (Miller and Larsen 1981), and post-depositional changes in the trace element content of bone from the site (Nelson and Sauer 1984) have also been completed.

The osteological and mortuary analyses indicate that most characteristics of the Black Earth Archaic material are consistent with those observed for other Archaic populations in the eastern U.S. (Bassett 1982 and Lynch 1982). The demography of the Black Earth sample is characterized by high infant but low weanling mortality; a high ratio (1.5:1) of males to females until late adulthood; and a short life expectancy, at birth, of 24 years (Bassett 1982). Analysis of pathologies revealed a high incidence of fractures (15%); the prevalence of osteoarthritis and osteophytosis in individuals past midadulthood; and little stress, as indicated by Harris lines, enamel hypoplasia, etc. (Bassett 1982). However, Bassett reports a high incidence of "osteitis," which he attributes to a "treponemal-like infection, tuberculosis or some other disease(s)" (Bassett 1982: 1075). The dentition is characterized by high rates of attrition and a high incidence of abscesses, but a low incidence of caries (Bassett 1982). Bassett concludes that the osteological analysis "generally reinforced most of the expectations about Archaic populations" (Bassett 1982: 1075).

Unfortunately, the small sample size of the Woodland component burials limited a comparison between the Woodland and Archaic samples. However, Bassett reports that "the two groups appear to be quite similar" (Bassett 1982: 1075).

The mortuary analysis also reinforces previous studies of Archaic burial patterns (Lynch 1982). The differential treatment of individuals at burial can be largely explained by age, sex, and presumably, personal attributes (Lynch 1982). The Woodland burial sample, although small, also seems to represent an egalitarian social system (Lynch 1982).

In summary, the Black Earth site represents a long period of occupation dating to the Middle Archaic nearly 6000 years ago. It yielded a large Archaic and small Woodland burial component. The skeletal samples are in good to excellent condition, and studies of descriptive osteology, demography, pathology, and mortuary behavior have been reported.

Dickson Mounds, Larson Phase: Maize Agriculture

Dickson Mounds is a prehistoric site situated on the bluffs overlooking the Illinois River and located about one mile from the confluence of the Illinois and Spoon Rivers (Figure 1). It is bordered by the river valley on the east and by gently rolling plains to the west. The environment is one of abundant flora and fauna, good water supply, favorable climate, and rich soil (Harn 1971). Although almost every phase of Midwest prehistoric development is represented at or near Dickson Mounds, only Middle Mississippian (Larson Phase) burials were sampled for the present study. The Larson Phase had been dated to the period 1225-1300 A.D., and represents a period of at least partial dependence on cultivated food (Harn, personal communication).

The Middle Mississippian in the central Illinois River valley was preceded by generalized hunting-gathering adaptations during the Archaic, followed by a period of "intensive harvest collecting" of certain wild foods during the Woodland periods (Struever 1968). Faunal remains from the Woodland periods at Dickson Mounds include white-tailed deer, elk, beaver, and smaller mammals, as well as wild turkey, prairie chicken, and aquatic birds (Harn 1971). Nuts, berries, and seed plants were also abundant.

Despite these favorable ecological conditions, the lifeways of the Woodland populations in this region were altered after about 1000 A.D. by the influence of the Mississippian culture developing farther south at Cahokia (Harn 1971). Harn contends that while the practice of maize agriculture is evident at Dickson Mounds by 1250 A.D., there was still an orientation toward wild foods (Harn 1975). However, for at least part of the year, maize probably played a major role in the diet of Larson Phase populations (Harn, personal communication). Lallo and Rose (1979) suggest that maize played an important role in the daily diet, and Gilbert concludes that the Middle Mississippians' "dependence upon maize was perhaps greater than conceived by Harn" (Gilbert 1975: 40). With this difference of opinion in mind, the subsistence base of the Larson Phase will be described, for the present study, as maize agriculture. That is, for at least part of the year, maize was an important dietary staple.

Gilbert (1975) also suggests that dependence on maize may have had a negative effect on the diet of the Middle Mississippians at Dickson Mounds. He explains this position as follows:

> Considering population increase, possible competition for game animals, possible trading of meat and/or hides, no apparent intensive exploitation of riverine resources and adoption of Mississippian cultural patterns, it does not appear unreasonable to assume that a decline in the quality of the diet may have ensued. The addition of maize as a ceremonial item may well have been transformed into a potentially predominent [sic] staple which permitted, and perhaps encouraged, a dietary protein reduction (Gilbert 1975: 40-41).

This proposition is corroborated in a general sense by other studies of prehistoric agriculturalists that indicate that these populations may have been under "chronic nutritional stress" (Martin and Armelagos 1979). The implications of this situation for the Dickson Mounds sample, especially with regard to cortical loss, were discussed in Chapter II.

A sample consisting of 34 adult males was obtained from the Larson Phase population for the present study. This sample was made available by Alan Harn of the Dickson Mounds Museum, part of the Illinois State Museum system. Of the 34 specimens samples, six were eliminated because age was indeterminable. The femora of the sample specimens were in good condition.

The osteological analysis of the Dickson Mounds skeletons was directed by Professor George Armelagos of the University of Massachusetts, Amherst (Harn and Armelagos, personal communications). The resulting data are on file at the Dickson Mounds Museum, Illinois. The adult skeletons were independently aged and sexed by D. VanGerven, B. Gustav, and J. Lallo (Gilbert 1975).

The skeletal biology of the Dickson Mounds population is reported in an unpublished dissertation by Lallo (1973). Some of Lallo's findings on stress, disease, and mortality are published, jointly, with Rose (Lallo and Rose 1979). They conclude that the transition to increased reliance on maize during the Middle Mississippian period at Dickson Mounds was accompanied by an increased level of stress. This is reflected in patterns of growth, disease, and mortality.

The authors observed a greater rate and severity of infectious disease, growth retardation, and other indicators of stress among the Middle Mississippian sample than among earlier samples (Lallo and Rose 1979). Analysis of dental pathology indicated that Middle Mississippians had a higher frequency of histological defects, which reflects the level of stress on the population, than did earlier groups (Lallo and Rose 1979). Demographic studies indicated that the Middle Mississippian population experienced higher mortality, and shorter life expectancies, than did earlier groups (Lallo and Rose 1979). These data suggest that the transition to reliance on maize agriculture resulted in nutritional and related stress during the Middle Mississippian at Dickson Mounds.

Another study of the skeletal sample from Dickson Mounds is an analysis of the trace element content of bone by Gilbert (1975). He employed trace elmeent analysis to test the presumed dietary changes which occurred from the Late Woodland through the Middle Mississippian periods. He found that only one element, zinc, was a useful dietary discriminator: it declined over the time period of interest. This information, in conjunction with the patterns observed for other trace elements, indicated a dietary shift based on a reduction in animal protein (Gilbert 1975). Gilbert suggests that the decline in animal protein in the Middle Missippian period "occurred predominately among males" (Gilbert 1975: 199). He observed that zinc (and other element) concentrations did not change significantly among females. He explains that this may indicate that males had greater access to meat (through hunting), or that they controlled its distribution and consumption (Gilbert 1975: 200).

Gilbert's conclusions about the incidence of osteoporosis at Dickson Mounds are germane to the present study. However, Gilbert recognized that the method he employed for determining bone loss (using radiographs) was "regretably but necessarily imprecise" (Gilbert 1975: 162). He found that males from the Late Woodland exhibited a greater rate of bone loss than did those from the Middle Mississippian. He concludes, tentatively, that "ingestion of animal protein may hasten skeletal involution" (Gilbert 1975: 198). However, a comparable change was not demonstrated for females, which Gilbert attributes to the lack of a substantial dietary change among females.

As will be discussed in Chapter VI, the results of the present study conflict with Gilbert's. That is, greater bone loss is reported for the Middle Mississippian than for an earlier (Archaic) hunting-gathering population. However, two important differences between the two studies must be recognized. First, the present study includes only the Middle Mississippian from Dickson Mounds, and this is compared with the Archaic (not the Woodland) from a different site. Second, a more reliable method of determining bone loss was employed in the present study. As Gilbert himself recognizes, radiographic investigations of bone loss are inferior to other (more direct) methods of measurement (VanGerven et al. 1969; Buikstra and Cook 1980).

In summary, a sample of 34 adult males was obtained from Dickson Mounds, Larson Phase, representing a Middle Mississippian population. The relative importance of maize in the diet has been debated, but it is clear that these Middle Mississippians were at least partially dependent on maize agriculture.

The transition to maize agriculture at Dickson Mounds was apparently characterized by nutritional stress, which affected the health status and demography of the population (Lallo and Rose 1979). According to Gilbert (1975), the reduction in animal protein in the diet may have affected males more than females. Gilbert also suggests that males from the Middle Mississippian exhibit less bone loss than do those from earlier periods. The conflict between this conclusion (and its attendant problems) and the results of the present study is discussed.

Fletcher Site: Maize Agriculture

The Fletcher site is a mid- to late-eighteenth century burial site located on the west bank of the Saginaw River in Bay City, Michigan (Figure 1). It has been dated to the mid-1700's on the basis of comparative artifact types and ethnohistoric accounts of population movement (Mainfort 1977; Nelson n.d.). The skeletal sample probably represents a northern or central Algonquian population (Sauer 1974; Mainfort 1977; Nelson n.d.).

Little is known about the diet of the Fletcher population because of the dearth of floral and faunal remains. However, a generalized model of subsistence may be inferred from ethnohistorical information about the Ojibwa and/or Ottawa, the group(s) who probably utilized the cemetery (Mainfort 1977; Nelson n.d.). This model involves hunting and gathering wild foods during the summer and winter seasons, with spring planting and fall harvesting of a few cultigens, such as squash and corn (Kinietz 1972). The population appears to have been only semi-sedentary, although there is no evidence from the historic occupation of the site itself to support or refute this ethnohistorical implication.

Despite certain similarities with the subsistence described in the above section for the Dickson Mounds sample, the superstructure (mound-building, ceremonial centers, etc.) which accompanies maize agriculture at Middle Mississippian sites is absent at the Fletcher and other early historic Michigan sites. One interpretation of this difference is that the population represented at Fletcher was less sedentary and less dependent on food production than that at Dickson Mounds. On the other hand, given the inclusion of cultigens in their diet, the Fletcher site population differs from the generalized hunting-gathering population represented by the Archaic sample from the Black Earth site. Therefore, for the purposes of the present study, subsistence at the Fletcher site is described as maize agriculture.

The skeletal sample from the Fletcher site consists of at least 93 individuals (Sauer 1974). Because the condition of many of the skeletons is poor or fragmentary, however, only seven adult males and 14 females were included in the sample. Of these, only 22 females could be assigned to an age group. The male sample was eliminated due to its small size.

Physical anthropological research on the Fletcher site material includes general osteological and dental analyses (Sauer 1974; Tordoff 1972), and studies of social organization based on nonmetric traits (Nelson n.d.) and mortuary behavior (Mainfort 1977). These studies are unpublished theses and manuscripts.

Sauer (1974) has suggested that the Fletcher population was subjected to nutritional stress resulting from contact with Europeans. As native populations developed new economic relationships with Europeans, they often exchanged products of subsistence for goods of little or no nutritional value (Sauer 1974). These included weapons, tools, liquor, and sugar.

It is interesting to note that Gilbert (1975) suggested a similar nutritional decline during the Middle Mississippian at Dickson Mounds that resulted, partly, from the exchange of meat and hides for trade goods. In both populations, presumably, the decline in animal products in the diet was accompanied by an increased dependence upon maize. For the reasons discussed in Chapter II, dependence upon maize as a dietary staple is associated with nutritional stress. In the case of the Fletcher population, the consumption of alcohol may have exacerbated the malnutrition, and contributed to the high incidence of osteoporosis noted by Sauer (Ortner 1978).

According to Sauer, there is evidence of nutritional stress in four characteristics of the Fletcher population (Sauer 1974). First, the high incidence of osteoporosis was detected using morphoscopic and radiographic assessment of cortical thinning. Second, the mean stature for males and females is less than for other Native American skeletal populations. Third, older individuals are underrepresented, which may suggest a short life expectancy in the population (Sauer 1974). Fourth, a high frequency of enamel hypoplasia, which affected 81% of the individuals in the sample, also indicated that the population suffered nutritional stress (Tordoff 1972).

Other studies have suggested that some aspects of traditional sociopolitical organization and settlement patterns may have been disrupted by contact with Europeans (Nelson n.d.; Mainfort 1977;

Hickerson 1966). For example, larger multiclan villages formed in response to the fur trade (Hickerson 1966).

In summary, the Fletcher skeletal sample represents a mid-eighteenth century Algonquian population that was partially dependent on maize agriculture. Studies indicate that it was subjected to nutritional and other stresses resulting from European contact.

CHAPTER IV

HYPOTHESES

Introduction

Differences in the patterns of changes in cortical bone within and between populations have been noted by other researchers (see Chapter II). Many different explanations have been proposed to account for this variation. In general, variability among populations may be explained by genetic factors, or by environmental factors, or both. Because these factors interact, it is often difficult to sort out the two sources of variation (see Underwood 1979). Complicating the problem further is the fact that environmental factors, among human populations, include natural as well as cultural variables. For example, cortical loss is believed to be affected by diet and disease, but also by behavioral factors such as activity levels and lactation intervals (Garn 1970 and 1973; Ericksen 1976; Thompson and Hey 1981, for example). Among humans, culture, environment and biology are intimately connected.

One step toward the development of a predictive model of human variation is to test specific hypotheses based on one or more of the proposed variables. In this study it is proposed that diet plays a significant role in the patterning of cortical gain and loss. The basis of this contention is recent medical, nutritional, and anthropological research, as discussed in Chapter II. The present study is mainly concerned with inter-population variation: most of the hypotheses proposed in this chapter concern the comparison of populations which represent different subsistence regimes, and, hence, different diets. The remaining hypotheses concern intra-population (age and sex) variation in cortical loss, which has been observed in virtually all study populations (see Chapter II).

The hypotheses presented in this chapter are scientific, rather than statistical, hypotheses. That is, they are statements which attempt to explain certain observations or phenomena, and are phrased in a predictive way so that they are testable. Statistical hypotheses, on the other hand, are statements about population parameters; they are "almost never equivalent to the hypotheses of science," although they are "implied by scientific hypotheses" (Hays 1973: 335). In the present study, where differences in means are to be tested statistically, then the statistical hypotheses are implied by the scientific hypotheses. The null hypotheses would state that there is no difference between the mean values of the variables. The alternative hypothesis would state that there is an inequality between means, reflecting the specific prediction in the scientific hypothesis. Therefore, the working hypotheses presented in this chapter imply the alternative to a null hypothesis which may be tested statistically.

If the hypotheses are supported by the data, then it will be suggested that variations in cortical loss in the three populations are due largely to environmental, rather than to genetic, factors. More specifically, dietary differences, which are the basis for the proposed comparisons, may make a major contribution to this variation.

However, because factors interact, as discussed above, behavioral variables such as levels of physical activity, and pregnancy and lactation practices, will be considered.

If, on the other hand, the hypotheses cannot be supported by the data, then other explanations must be proposed. If, for example, there were no apparent differences between the hunter-gatherer and agriculturalist samples, then, statistically, the null hypothesis would not be rejected. In this case, one of the following situations would be true:

1. There are, in reality, no significant differences between the samples.
2. There may be some significant differences between the populations, but some alternative hypotheses, other than those based on diet, may be true.

In either case, hypotheses based on genetic differences or similarities must be entertained. If, in the first case, no population differences were apparent, it might be that the populations are genetically homogeneous. In the second case, genetic differences between the three populations might account for presumed differences in the patterning of cortical loss at the sites. In this case, a study of genetic relationships between the three groups would be indicated.

In order to test the hypotheses proposed in the following sections, data from the measurement of bone mineral content (BMI), cortical thickness (CT/CIRC), and bone density (BMI/CT) will be evaluated (see Chapter V). The first set of hypotheses concerns intrasite variation: that is, the relationship between cortical loss, and age and sex. The second set of hypotheses examines population differences in the gain and loss of cortical bone.

Hypotheses: Intrasite Variation

The first hypothesis concerns changes in cortical bone after midadulthood, which were discussed in Chapter II. It is stated as follows:

> HYPOTHESIS 1: Mean bone mineral (BMI), cortical thickness (CT/CIRC), and bone density (BMI/CT) will be lower in individuals past midadulthood than in early adulthood.

If this is true, then one-tailed t-tests will indicate that there is a significant difference between the younger and older age groups[1] in the mean values of the variables listed above. The alternative (statistical) hypothesis will state that the means of the older groups are less than those of the younger groups. This hypothesis will be evaluated with data from each of the three sites.

Because of the limited samples available from Dickson Mounds and Fletcher, this hypothesis will also be evaluated for those sites in two other ways. The Fisher's Exact test, which is appropriate for small samples, and an evaluation of percentage changes in the means will be employed. These methods are described further in Chapter VI.

The second hypothesis concerns sexual dimorphism in the pattern of cortical loss. This hypothesis can be evaluated with data from the Black Earth site only, as each of the other two samples consists of only one sex. The hypothesis, based on information discussed in Chapter II, is stated as follows:

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[1]Assignments of individuals to age groups are described in Chapter V. Age groups 1 through 3 represent "younger" individuals. Since age groups 3 and 4 represent middle age, age groups 4 and 5 consist of "older" individuals who are past midadulthood.

HYPOTHESIS 2: Females lose more bone than do males.

In order to evaluate this hypothesis, the percentage change after midadulthood in the quantity of cortical bone (as measured by bone mineral index, cortical thickness index, and bone density index) will be calculated for each sex. It is expected that females will show a significantly higher percentage of bone loss with age than males do.

Hypotheses: Variation Between Populations

The next two hypotheses, which consider the male and female samples separately, concern differences between the hunting-gathering sample from Black Earth and the agriculturalists from Dickson Mounds and Fletcher. The variables to be examined are bone mineral index (BMI), cortical thickness index (CT/CIRC), and bone density index (BMI/CT). Each sample (single-sex) will be subdivided into "younger" and "older" groups in order to compare samples with similar age distributions.

The first two hypotheses are stated as follows:

HYPOTHESIS 3: The female samples (younger and older) from the Black Earth site will have mean values for bone mineral, cortical thickness, and bone density which are significantly different from those of the females from Fletcher.

HYPOTHESIS 4: The male samples (younger and older) from the Black Earth site will have mean values for bone mineral, cortical thickness, and bone density which are significantly different from those of the males from Dickson Mounds.

In order to test these hypotheses, two-tailed t-tests will be performed. If a test is significant, then the null hypothesis--that there are no differences between the means--is rejected. The alternative hypothesis, which would be tentatively accepted, will not specify the direction of the difference, but rather an inequality of the two means.

The last two hypotheses deal with differences in the patterns of cortical loss between the populations. The amount and timing of cortical loss are the variables which will be examined. The hypotheses are stated as follows:

HYPOTHESIS 5: The pattern of cortical loss among males will be different in the two populations, Black Earth and Dickson Mounds.

HYPOTHESIS 6: The pattern of cortical loss among females will be different in the two populations, Black Earth and Fletcher.

If these hypotheses are true, then the following analyses will clearly indicate a difference in the amount and timing of cortical loss between each pair of sites: graphic comparisons of the data with respect to the mean bone mineral (BMI), cortical thickness (CT/CIRC), and bone density (BMI/CT) of each age group; and data concerning the percentage of bone lost after midadulthood.

In Chapters VI and VII, the significance of the patterns which emerge will be discussed, and generalizations about the observed trends will be suggested. Specifically, these will be examined with regard to the question of whether hunter-gatherers lose more bone than do primary agriculturalists.

Summary

In this chapter, six hypotheses were proposed, and methods of testing them were described. Two of the hypotheses concern intra-site (age and sex) variation in bone loss. The other four hypotheses involve variation in the gain and loss of cortical bone between populations. The hypotheses are presented as scientific, rather than statistical, hypotheses, although the latter are implied.

It is suggested that it is mainly dietary differences between the sites which account for the cortical differences. However, because natural, cultural, and genetic variables interact in human populations, several additional factors were discussed.

CHAPTER V

MATERIALS AND METHODS

Data Collection

Femoral cortical samples were obtained from samples of adults from the Black Earth, Dickson Mounds (Larson Phase), and Fletcher sites. A high-speed craft drill with an emergy saw attachment was used to remove the samples.[2] A rectangular shape approximately 1 cm. by 1.5 cm. was cut into the anterior shaft of each femur, and a piece of cortex, intact, with trabeculae still adhering in some cases, was removed (Figures 2-4). The site of sample removal was midway between midshaft and the proximal end of the popliteal surface (a point projected through the bone to the anterior surface). This location was selected for several reasons: removal of cortical bone at that site does not obscure any osteological landmarks; and at least two studies (Ericksen 1979 and VanGerven et al. 1969) indicate that most age-related endosteal resorption in the femur is anterior-posterior, and

[2]All of the femoral cortical samples were removed by the author. The following information was also determined directly by the author: age and sex of the Black Earth and Fletcher material; whole-bone measurements and pathologies of the Black Earth and Fletcher material; and, bone mineral and cortical thickness measurements of all of the samples. Osteologists under the direction of Professor George Armelagos, of the University of Massachusetts at Amherst, determined the age and sex of the Dickson Mounds material. These data are on file at the Dickson Mounds Museum. Professor Norman Sauer of Michigan State University corroborated the author's estimations of age and sex for the Black Earth and Fletcher sites.

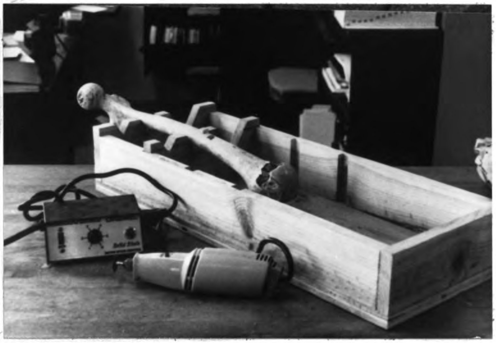

Figure 2.--Craft drill and apparatus used in excision of cortical samples.

Figure 3.--Method used to excise cortical samples from femora.

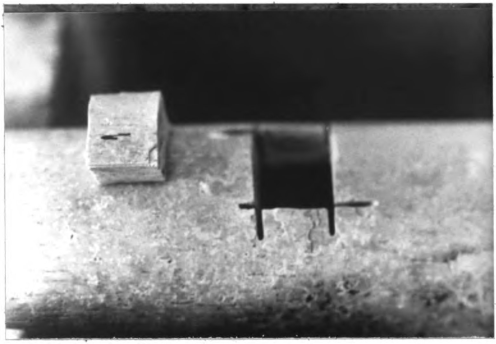

Figure 4.--Bone sample removed from femoral cortex.

that more medullary cavity expansion occurs in the diaphysis than in the metaphyses.

Cortical samples were removed from all of the adults from the Black Earth site for which femora were available and complete enough for identification of the specified landmark. Pathological specimens were included unless the landmark was obscured in some way as a result of the pathology. A total of 54 males and 45 females were sampled, representing both the Archaic and Woodland components and some burials of unknown cultural affiliation (which were eliminated for the analysis). All of the adults from Fletcher (7 males and 14 females) whose femora were complete and in good enough condition for sample removal were utilized for this study. Cortical samples were also obtained from 34 males from Dickson Mounds; these specimens were selected and made available for this study by Mr. Alan Harn of the Dickson Mounds Museum, Illinois.

As was discussed in the introduction, it was impossible to obtain sample sizes from Dickson Mounds and Fletcher that were sufficiently large for the statistical tests of choice. That is, although the hypotheses were formulated, and appropriate statistical tests selected, before the data were collected,unforeseen circumstances severely limited the availability of large samples. Alternative analytical methods were selected for the data from Dickson Mounds and Fletcher, and are discussed in Chapter VI.

Before the cortical samples were removed from each femur, two measurements were obtained--circumference at the site of sample removal, and maximum morphological length of the femur. The sex and age of each specimen were determined in the manner outlined below. Pathologies also were noted for the Black Earth sample.

The sex of each Black Earth specimen was determined on the basis of gross morphological criteria, expecially those involving the skull and pelvis. Where both of these were available for sexing, the Phenice method (1967), based on three features of the pubis, was considered to be the most reliable (Kelley 1978). The results of Phenice's study (1967) indicate that the method is an accurate predictor of sex in 95% of cases. Whenever possible, the shape of the pelvic outlet, the breadth of the sciatic notch, and the presence of a pre-auricular sulcus (see Bass 1974) were also considered, but were secondary to the criteria of the Phenice method.

Features of the skull were examined next. In addition to the relative robusticity of the cranium and face (see Bass 1974), the degree of gonial eversion was evaluated, as there appeared to be a significant degree of sexual dimorphism in this characteristic in this population. That is, gonial eversion was more pronounced in specimens which the pubic criteria had indicated were males, and conversely.

When bones from both of these regions were missing or extremely fragmentary in an individual, sex was not assigned. When the data from the skull and pelvis were ambiguous or contradictory, the overall size and robusticity of the specimen were considered, including the size of the femoral and humeral heads (Bass 1974).

The Fletcher material was assessed in similar fashion. Sex determination was corroborated in each case (from Black Earth and

Fletcher) by Professor Norman Sauer, Michigan State University. The sex determination for the Dickson Mounds sample was made by osteologists at the University of Massachusetts under the direction of Professor George Armelagos (Harn, personal communication).

The age of each specimen in the Dickson Mounds sample was also determined by osteologists at the University of Massachusetts. According to Armelagos (personal communication), ages were established by seriating the pelves on the basis of degenerative change, and employing McKern and Stewart's method (1957).

The determination of age for the Fletcher specimens was reported by Sauer in an unpublished Ph.D. dissertation from Michigan State University (1974). Sauer assigned individuals to age categories on the basis of several criteria, including epiphyseal union, dental attrition, and degenerative changes. In the course of the present study, these age estimates were re-evaluated by similar methods and by evaluating dental attrition using the method detailed by Brothwell (1981), and described below. These techniques were also applied to the Black Earth sample, and the resulting age determinations are given in the form of age categories and ranks.

While it is tempting to assign specific ages, or age ranges, to skeletal specimens, as was done for the Dickson Mounds sample, absolute values (years of age) may not be very reliable. One problem is that many aging techniques are applicable only within a certain range and sex. For example, McKern and Stewart's pubic symphyseal stages, while quite reliable, are sex-specific and useful up to about age 40 (McKern and Stewart 1957). The problem with some other common aging techniques, such as the assessment of suture closure, is that they have been shown to be less accurate than dental and pubic criteria (Krogman 1962). Because of these problems and the fragmentary nature of some of the remains used in this study, it was decided that ranking and grouping individuals into age categories would be more reliable than assigning discrete values to each.

Age categories ranged from "1" to "7", where "1" and "2" represent young adults; "3" and "4" represent middle age; and "5" represents older adults. Group "6" contains adults whose ages are considered to be past midadulthood, and group "7" are adults of indeterminate age. As mentioned above, the assignments of individuals to these age groups was based on epiphyseal union, degenerative changes in the skeleton (such as osteophytosis and arthritis), and dental attrition (see Krogman 1962; Bass 1974; and Stewart 1979). Whenever possible, males were assessed using McKern and Stewart's (1957) aging kit for the pubic symphysis.

Specimens from the Black Earth and Fletcher sites were ranked by age in accordance with the method outlined by Brothwell (1981), which is based on dental attrition. It was not possible to rank the Dickson Mounds specimens because so many of the reported estimates were age ranges, and ranking these resulted in too few ranks with many tied ranks. Statistical manipulation of these data proved to be impossible.

The aging technique based on dental attrition employs a classification of attrition, ranging from slight enamel polishing through various stages of the exposure of dentine (Brothwell 1981).

The most extreme case of dental attrition would be wearing down of a tooth to the roots. These stages of attrition are recorded on the basis of a rating system, ranging from "1" (no wear) to "7" (roots only), as suggested by Brothwell (see Figure 5). This information is used to assess the amount of attrition which occurs in a given period of years, as determined by molar eruption and other aging criteria (see below).

In applying this technique, the wear on the first and second molars was examined in individuals who were estimated to be 16 years old on the basis of epiphyseal union and the absence of the third molar. For example, in the Black Earth sample, the amount of wear on the first molar (the "6-year" molar) of 16-year-olds is "2+" and on the second molar (the "12-year" molar) is "2". This indicates that it took 10 years (from 6 to 16 years of age) for a wear pattern of "2+" to occur, and four years for a "2" to occur. This assessment is continued for each of the molars in older and older individuals. Epiphyseal union was used to estimate age through age 31, when the sternal epiphysis of the clavicle is united (McKern and Stewart 1957), and pubic symphyseal metamorphosis was assessed wherever possible for males.

The step-by-step procedure is outlined as follows:

1. Wherever possible, the wear was evaluated on one first, second and third molar from the maxilla, and on one each from the mandible. Brothwell's (1981) classification was employed. The decision to use teeth on the right or left sides was based on the

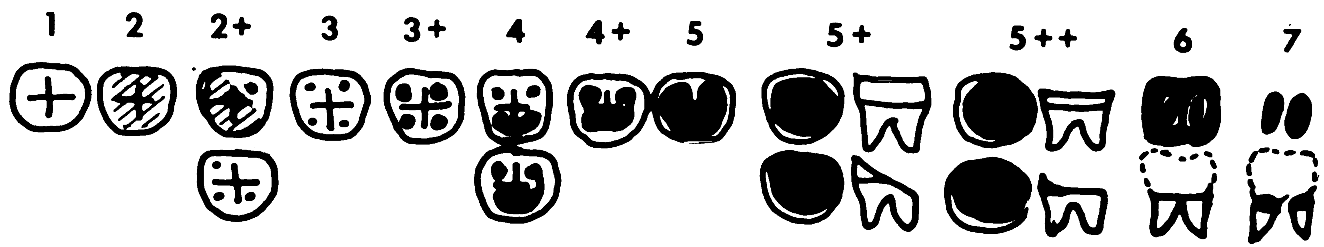

Figure 5.--Stages of dental attrition (after Brothwell 1981).

comparative condition of the individual teeth. There did not appear to be a systematic lateral bias to tooth wear.

2. The maxillary and mandibular scores for each molar were averaged. In most cases the scores were the same or very close unless there was a serious malocclusion, in which case the maloccluded side was omitted.

3. Based on the scores recorded for M-1, M-2, and M-3, individuals were ranked in order of least to most dental attrition. The scores of each specimen were recorded on a chart which listed each rating across the top. An "x" representing each of the three molar scores was placed under the appropriate rating. Ideally, as one moves to the right and down the chart, one encounters older specimens.

4. At the far right of the chart, the estimated age (given as a range in some cases, and as a descriptive category in others) was listed for each individual. These were the estimates derived from gross morphological criteria from the whole skeleton, as described earlier. As a check on these assessments, age estimates based on pubic symphyseal metamorphosis were compared with them wherever possible. In 21 out of 24 cases there was good agreement among the three methods. In two of the three remaining cases, the pubic symphyseal age estimate is slightly lower than otherwise, but within five years of the other two estimates. In the remaining case, the pubic symphyseal age estimate agrees with the gross morphological criteria, both of which are slightly higher than the dental assessment (but within 5 years). The dental wear pattern on this specimen was unusual.

5. Based on all these criteria, age groups were established. At the Black Earth site, the "early" adults range in age from 18 to 30 years; the "middle" adults from 31 to 46 years; and the "late" adults are over 46 years old. The "early" and "middle" categories were each divided further into two categories. The result is that early adults have a categorical age of "1" or "2", middle adults "3" or "4", and late adults "5".

These steps were followed, in general, for estimating the age of the Fletcher site specimens. The latter, however, constituted a much smaller sample than the Black Earth site. Rates of dental attrition with age appeared to be comparable at the two sites, although the limitation imposed by a small sample size on this kind of analysis must be acknowledged. The age estimates reported for the Dickson Mounds sample were categorized into age groups on the basis of the categories estabished for Black Earth (i.e., groups "1" through "5", with corresponding age ranges). Although dental attrition was not assessed for the Dickson Mounds sample, the classification of specimens into age groups was based on pubic symphyseal criteria. This is consistent with the classification methods used at the other sites, as those age estimates were also checked against pubic symphysis data.

The next step in the analysis was to obtain measurements on the cortical samples themselves. The methods employed are detailed in the following section.

Bone Mineral Analysis

One problem which must be addressed in any study of the composition of disinterred bone is whether the material was subject to postdepositional alteration (Nelson and Sauer 1984). One potential method of evaluating diagenesis for the present study of bone mineralization is to employ histomorphometric techniques. Unfortunately, a preliminary attempt to make thin sections of the Black Earth material was unsuccessful due to the fragility of the bone (Everett Bassett, personal communication). Since macroscopic inspection of the cortex is considered to be an inadequate evaluation of postdepositional change (Buikstra and Cook 1980), an indirect method of evaluation was devised.

This method involves the performance of F tests for significant differences between variances of bone mineral values at the three sites. It is based on the logical premise that there will be more variation in the variables (bone mineral index and bone density index) from a sample which was altered diagenetically than from a sample which was not altered. If there are no significant differences between the variances of the three samples, then it is assumed that none of the samples was affected by postdepositional changes.

In order to apply this technique, the samples were subdivided into males and females and into younger and older age groups. The latter grouping was based on the division of the samples at age groups 3 and 4, which represent the two "middle age" groups. Thus, groups 1, 2, and 3 represent pre-midadulthood, and 4 and 5 represent post-midadulthood.

The four resulting comparisons are Black Earth and Dickson Mounds males, both younger and older; and Black Earth and Fletcher females, younger and older. The variables are bone mineral index and bone density index, which incorporate the measurement of the bone mineral content of the specimens.

With alpha set at 0.05, two-tailed F tests resulted in no significant differences in either variable in any comparison (see Tables 1 and 2). Therefore, it is assumed that the cortical samples used in this study have not been altered diagenetically with respect to their bone mineral content.

The femoral cortical samples were analyzed on a Norland Model 278 Bone Densitometer. This instrument employs photon absorptiometry to estimate the bone mineral content, bone width, and bone mineral index of a specimen.[3] The underlying principle of photon absorptiometry is that radioactive isotopes, as they decay, emit energy which may be measured in units known as "photons." Photons are quanta, or "packages," of radiant energy. The reason that radioactive isotopes decay is that they are unstable atoms whose nuclei have unfavorable neutron to proton ratios. They return to stability by the conversion of neutrons to protons or vice versa, and energy is emitted.

The Bone Densitometer has a monoenergetic radiation source (125I) which provides a photon beam. This beam is highly collimated

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[3]This technique is outlined in an Instruction Manual available from Norland Instruments, Fort Atkinson, Wisconsin. It is detailed in Cameron and Sorenson (1963).

TABLE 1.--F Tests: Comparison Between Black Earth (BE) and Dickson Mounds (DM) Males.

Variable	Sample	Mean	s.d.	N	F Value	Significance*
Bone mineral index	BE, Younger	.63	.090	21	1.01	--
	DM, Younger	.51	.089	14		
Bone mineral index	BE, Older	.58	.084	15	1.33	--
	DM, Older	.46	.097	14		
Bone density index	BE, Younger	1.22	.126	21	1.39	--
	DM, Younger	1.02	.106	14		
Bone density index	BE, Older	1.24	.108	15	1.90	--
	DM, Older	0.97	.149	14		

*Two-tailed F-tests, alpha = 0.05

TABLE 2.--F Tests: Comparison Between Black Earth (BE) and Fletcher (F) Females.

Variable	Sample	Mean	s.d.	N	F Value	Significance*
Bone mineral index	BE, Younger	.51	.076	13	1.20	--
	F, Younger	.36	.070	7		
Bone mineral index	BE, Older	.46	.072	12	1.08	--
	F, Older	.30	.075	4		
Bone density index	BE, Younger	1.28	.111	13	2.54	--
	F, Younger	1.10	.177	7		
Bone density index	BE, Older	1.34	.094	12	1.52	--
	F, Older	0.09	.115	4		

*Two-tailed F-tests, alpha = 0.05

as it leaves the source and again as it reaches the scintillation (flash of light) detector (see Cameron and Sorenson 1963). The detector apparatus measures the transmission of the photon beam.

A bone placed in the path of the photon beam absorbs some of the energy, the amount of which is proportional to the mass of the bone mineral (see Cameron et al. 1968). The scintillation detector is attached to a microprocessor which estimates the density of the bone on the basis of the degree to which the bone's presence attenuates the photon beam. The microprocessor generates an absorption curve, the area of which is proportional to the bone mineral content (g/cm) of the specimen. The computer calculates the value of the bone mineral content, and provides a measurement of bone width[4] (cm) and a bone mineral index (bone mineral content divided by bone width) (see Figure 6).

According to the instruction manual, the precision of the instrument is ±2.5%. The precision of the instrument used in the present study was evaluated in two ways. First, a sample chosen at random (Burial 22 from Black Earth) was scanned--placed in the path of the photon beam for evaluation--28 times on the first day of the data analysis. The sample was repositioned in the scan path on at least every fourth scan. Some of the measurements were taken after other samples were evaluated. The mean, standard deviation, and

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[4]"Bone width" refers to the length of the scan path on the bone. In measuring bone mineral _in vivo_, it is actually the width of the whole bone being measured. In the present study, it is the width of the cortical sample placed in the scan path, which is parallel to the longitudinal axis of the femur.

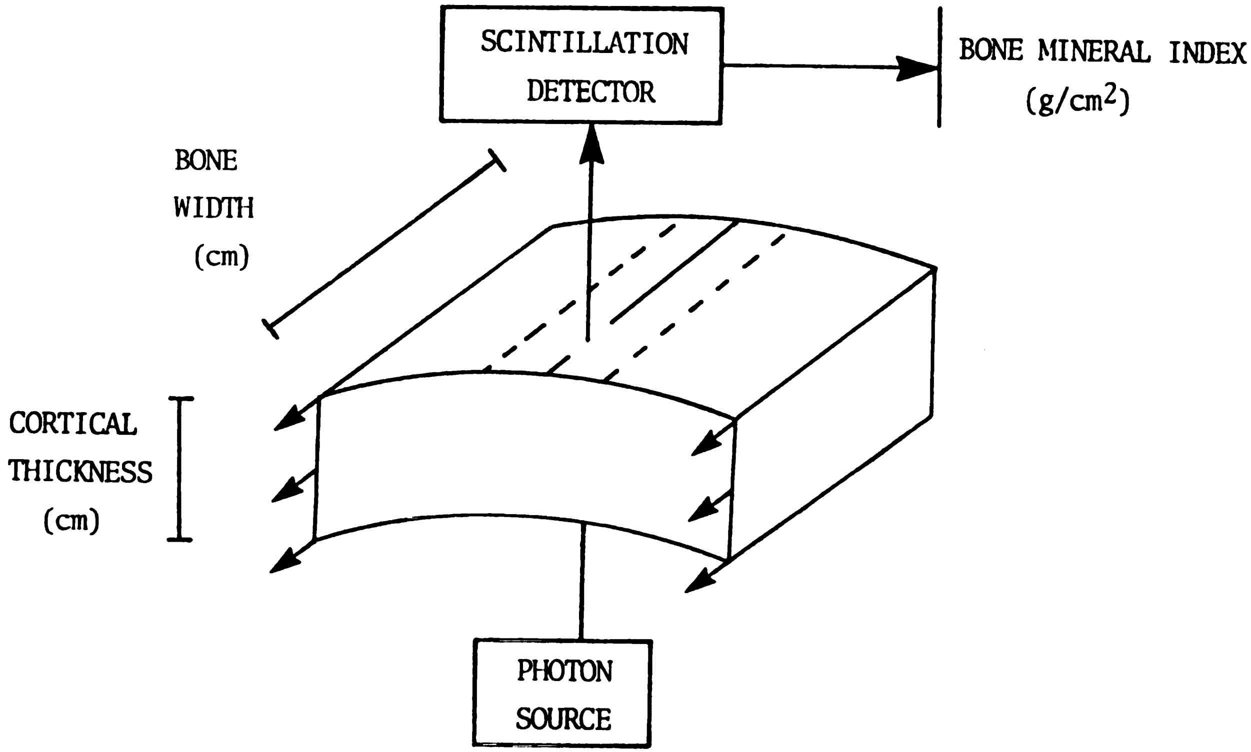

Figure 6.--Diagrammatic representation of bone mineral analysis; location of other measurements indicated.

range of the values were calculated. The mean bone mineral index for 28 scans of Burial 22 was .708 g/cm^2; the standard deviation was 3.6, and the range was .701-.716 g/cm^2. All of the data fell within 1% of the mean.

The second method of evaluating the precision of the instrument throughout the duration of the study involved scanning Burial 22 several times each day (that analysis took place). The data analysis was done during a three-week period in March 1983. A total of 37 measurements of the Burial 22 sample was obtained. The mean bone mineral index was .718 g/cm^2, with a standard deviation of 13.5. The range was .696 to .739 g/cm^2, and all data fell within 3% of the mean.

The results from both methods of evaluating precision were very close to the value given by Norland Instruments, ±2.5%. The manual also states that the accuracy of the instrument (i.e., how close the instrument's measurement is to the true value) is difficult to assess, but in the present study it is the relative values that are important. Since all of the samples were analyzed with the same instrument within a span of three weeks, the measurements are internally consistent and therefore comparable.

The Norland manual describes bone mineral content as a measure of "linear mass density," given in terms of grams per centimeter of bone.[5] The computer also calculates the "bone width," or length of the scan path, in centimeters. However, the technique does not

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[5]The width of the scan path is approximately 4 mm., according to the manual; but the computer calculates the bone mineral content on the basis of a width of one centimeter.

provide any information about the thickness, or depth, of the bone. Thus, "if the bone could be crushed flat, while maintaining the same width dimension, the bone mineral distribution would 'look' identical to the photon beam" (p. 12, Model 178 Instruction Manual). In order to obtain this depth dimension, cortical thickness was measured directly on each specimen using Vernier calipers. Figure 6 illustrates the location of each measurement.

As described earlier, the instrument's computer provides a bone mineral index (g/cm^2) which is the bone mineral content (g/cm) divided by the bone width (cm). By dividing this index by cortical thickness, one obtains a three dimensional value in terms of g/cm^3. This index is an estimate of bone density (mass per volume), and represents the amount of bone mineral which would be present in a cubic centimeter of bone. As will be discussed in later chapters, this index lends great insight into the patterns of bone mineral loss which are observed in the three populations.

Because the instrument's functions are highly automated, the operation of the Bone Densitometer is technically simple. At the beginning of each session, the instrument calibrates itself using a phantom bone of known width and density. It also reports the count rate of gamma rays emitted from the radioactive source, indicating the strength of the source. The source gets weaker as it decays and results in more "scatter" in the bone mineral content and bone width values (p. 11, Model 178 Manual). That is, with a weaker source, less energy reaches the detector-computer apparatus. Since the microprocessor bases its estimates of bone mineral content and bone width on the relative amount of energy received by the scintillation detector, these values may be less accurate or less precise when the source is weak. This was not a problem in the present study, as the count rate during the period of the data analysis ranged from 29,000 to 37,000 counts per second. The manual indicates that a count rate over 1,000 counts/second is necessary for obtaining reliable results.

After the calibration of the instrument was completed, the scanning of the cortical samples began. Each sample was positioned in the scan path such that the scanner moved along the longitudinal midline of each sample. At first, four scans were done on each sample. However, it became clear that there was so little variation between the values that only one scan would be necessary. This conclusion was based on an evaluation of 45 specimens which had been scanned four times each. The question asked was, how close to the average of the four scans was the initial scan? The difference between the mean value and the initial value was determined as a percentage, and the percentages from each of the 45 scans were averaged. The mean percent difference was 0.4%. That is, on the average, the difference between the initial value and the average of four consecutive scans was 0.4%. This was considered to be negligible, and only one scan was performed for each sample.

Two problems were encountered with the cortical samples. One is that many of the bones from the Black Earth site had an accretion of calcium carbonate which may have influenced the measurement of bone mineral content. Therefore, observable layers of the accretion were carefully removed with a dental pick. The second problem concerns the presence of trabeculae on some of the samples. This appeared to be minor, however, as the trabeculae were so fine in most cases that, compared with the dense cortical bone, their relative contribution to the bone mineral content would be minimal. In other cases, it was impossible to determine where trabecular bone, in thin layers, ended, and cortical bone began.

Cortical Thickness

After the bone mineral analysis was completed, the cortical thickness of each sample was measured. The jaws of Vernier calipers were closed onto the outer and inner surfaces, along the midline, of each bone sample. This measurement was taken along the same axis as that which was scanned by the Bone Densitometer. Trabeculae were carefully removed with a dental pick where necessary, in order to measure just the cortical bone.

An index was devised for cortical thickness because of an observation made by Garn (1970) and other researchers concerning the changes which occur concomitantly at a bone's two surfaces as cortex is gained and lost. He reported, and the present study corroborated, that apposition at the outer surface of a long bone continues throughout life (Garn 1970). That is, a bone's circumference enlarges as an individual ages. Therefore, cortical thickness reflects not only changes in the amount of cortical bone but, also, changes in the size of the bone.

For the present study, cortical thickness (CT) is divided by circumference (CIRC), taken at the site of sample removal. This index will reflect the changes in cortical thickness while controlling for outward cortical expansion.

Summary

This chapter provides a brief description of the nature of the samples used in this study (and described in more detail in Chapter III). It is mainly concerned with the methods used in selecting and removing the femoral cortical samples; assessing the age and sex of the specimens that were sampled; and applying photon absorptiometry to evaluate bone density. Some related issues were discussed, including the evaluation of postdepositional changes in the cortical samples, and the precision of the instrument used for the bone mineral analysis.

Throughout this chapter, a number of variables are defined. The following list summarizes these variables:

- MML: maximum morphological length of the femur (cm)
- CIRC: Circumference of femur, measured at the site of cortical sample removal (cm)
- BMC: bone mineral content (g/cm)
- BW: bone width (cm)
- BMI: bone mineral index (g/cm^2)
- CT: cortical thickness (cm)
- BMI/CT: bone density index (g/cm^3)
- CT/CIRC: cortical thickness index

CHAPTER VI

RESULTS

Introduction

In general, the results of this study support the hypotheses about interpopulatiohn variation proposed in Chapter IV. The individuals from the Black Earth site had denser, thicker bone, and lost less bone mineral after midadulthood, than did the individuals from Dickson Mounds and Fletcher. Different patterns of changes in these variables were also observed in the comparison of sites.

Each site was also examined for intra-population patterns in the gain and loss of cortical bone. The Black Earth site provided the only information on sexual dimorphism, since only the males were sampled from Dickson Mounds, and mainly females were available from Fletcher. However, the relationship between bone loss and age was evaluated for each site.

Whole bone measurements were also obtained from the femora which were sampled for the cortical bone analysis. These will be discussed first, because there is some evidence from at least one other study that body size affects bone mineral content (BMC). Mazess and Christiansen found that in samples of extant Danish and U.S. populations, "height, weight, and age influenced the BMC results" (Mazess and Christiansen 1982: 349). It is not clear, from their report, how much relative influence each of these variables had on the bone mineral results. It is obvious from the many studies discussed in Chapter II that age has a significant effect on bone mineral content. The potential problem which these suggestions pose for the present study is that if the samples are significantly different with respect to body size, then the comparisons of bone mineral content might be affected. While it is impossible to evaluate weight in the present study, the maximum morphological length of the femur is a useful indicator of stature (see Stewart 1979).

In order to investigate this problem, each sample was subdivided into "young" and "old." The former consisted of age groups 1, 2, and 3, and the latter of age groups 4 and 5. In each subdivision, males from Black Earth were compared with those from Dickson Mounds. T-tests for differences between each sample's mean maximum morphological length (femur) were performed (Table 3). It is not possible to compare females on femoral length because of the fragmentary nature of the Fletcher remains. Among both younger and older males, there were no significant differences in maximum morphological length of the femur.

To examine this problem another way, a Pearson product-moment correlation coefficient was obtained for the pair of variables, femoral length and bone mineral index. Only the Black Earth sample was large enough for this procedure. For both males and females, there was no significant correlation between the variables (alpha set at 0.01).

In summary, it was concluded that at least two of the samples were not significantly different in stature (Black Earth and Dickson

TABLE 3.--T-Tests: Maximum Morphological Length of the Femur Among Males at Black Earth and Dickson Mounds.

Site	Age	N	Mean (cm.)	s.d.	Significance*
Black Earth	Younger Adult	21	44.2	1.613	--
Dickson Mounds	Younger Adult	10	45.0	1.845	
Black Earth	Older Adult	12	44.7	1.898	--
Dickson Mounds	Older Adult	9	44.9	1.906	

*Two-tailed t-tests, alpha = 0.05

Mounds males). It can also be concluded that femoral length, an indicator of stature, is not correlated with bone mineral index (in the Black Earth site). Therefore, it will be assumed that the possible effect of body size on bone mineral content is not significant in the present study. It is suggested that sex, age, and diet are the significant factors which affect cortical bone.

In the next three sections, each of the three sites will be discussed separately, and the results of the intrasite analyses will be examined. The last part of this chapter concerns the results of the inter-population comparisons.

The Black Earth Site

For the purpose of the intrasite analysis, both the Woodland and Archaic components from Black Earth will be analyzed. There are three reasons for this. First, t-tests showed no significant differences between the two components for the bone mineral index, cortical thickness, bone density, maximum morphological length of the femur or circumference (see Tables 4 and 5). Second, the Woodland sample was so small (8 males and 11 females) that it could not be studied separately. However, the combined Archaic and Woodland samples provided a larger total sample, consisting of 46 males and 38 females. Combining the components allowed some statistical analysis, especially by age-group or age rank, that was not possible with smaller samples. Third, there is no evidence that the diet of the Woodland component contained any domesticated plants (see Chapter III). That is, both the Archaic and Woodland components represent a hunting-gathering subsistence strategy.

TABLE 4.--T-Tests: Comparisons of Archaic (A) and Woodland (W) Component Males at Black Earth Site.

Variables (units)	Component	Mean	s.d.	N	Significance*
Maximum morphological length, femur (cm)	A	44.4	1.711	36	--
	W	44.0	2.613	5	
Circumference, femur (cm)	A	8.7	.627	41	--
	W	8.2	.595	8	
Bone mineral index (g/cm^2)	A	.60	.089	41	--
	W	.62	.091	8	
Cortical thickness (cm)	A	.50	.085	41	--
	W	.52	.091	8	
Bone density index (g/cm^3)	A	1.23	.113	41	--
	W	1.22	.165	8	

*Two-tailed t-tests, alpha = 0.05

TABLE 5.--T-Tests: Comparison of Archaic (A) and Woodland (W) Component Females at Black Earth Site.

Variable (units)	Component	Mean	s.d.	N	Significance*
Maximum morphological length, femur (cm)	A	42.2	1.364	23	--
	W	41.2	1.552	5	
Circumference, femur (cm)	A	7.4	.439	32	--
	W	7.6	.531	11	
Bone mineral index (g/cm^2)	A	.46	.090	32	--
	W	.50	.079	11	
Cortical thickness (cm)	A	.36	.077	32	--
	W	.39	.078	11	
Bone density index (g/cm^3)	A	1.29	.132	32	--
	W	1.30	.162	11	

*Two-tailed t-tests, alpha = 0.05

The classification of burials into cultural components was discussed in Chapter III. Some of the burials, which lay in a transitional zone and were not associated with temporally diagnostic artifacts, were classified into an "unknown cultural affiliation" category (Jefferies 1982). Jefferies states that ". . . it is likely that this group contains a mixture of Archaic and Woodland burials" (Jefferies 1982: 187). Seven burials which were placed into this "unknown" group are included in the combined Archaic and Woodland sample for this part of the present study. These burials were originally designated either "probable" or "possible" Woodland burials by the late Dr. B. Mark Lynch (personal communication).

The first hypothesis to be tested with the combined Archaic and Woodland data from the site is stated as follows:

> HYPOTHESIS 1: Mean bone mineral (BMI), cortical thickness (CT/CIRC), and bone density (BMI/CT) will be lower in individuals past midadulthood than in early adulthood.

In order to test this hypothesis, one-tailed t-tests were performed, with alpha set at 0.05. Males and females were divided into "younger" and "older" groups comprised of age groups 1, 2, and 3; and 4, 5, and 6, respectively.

The younger group of males had the highest mean bone mineral index (0.64 g/cm^2) of any of the four groups (Tables 6 and 7). The mean of the older male group was 0.58 g/cm^2. Young females had less mean bone mineral than either male group (0.52 g/cm^2), and older females had the lowest bone mineral index (0.42 g/cm^2).

TABLE 6.--T-Tests: Comparison of Younger (Y) and Older (O) Age Groups Among Black Earth Males (Archaic and Woodland).

Variable (units)	Age	Mean	s.d.	N	Significance*
Bone mineral index (g/cm^2)	Y	.64	.086	26	*
	O	.58	.075	20	
Cortical thickness index	Y	.064	.011	26	*
	O	.053	.009	20	
Bone density index (g/cm^3)	Y	1.21	.132	26	--
	O	1.25	.100	20	
Circumference (cm)	Y	8.3	.520	26	*
	O	8.8	.588	20	

*One-tailed t-tests, alpha = 0.05

TABLE 7.--T-Tests: Comparison of Younger (Y) and Older (O) Age Groups Among Black Earth Females (Archaic and Woodland).

Variable (units)	Age	Mean	s.d.	N	Significance*
Bone mineral index (g/cm^2)	Y	.52	.070	20	*
	O	.42	.091	18	
Cortical thickness index	Y	.054	.011	20	*
	O	.043	.010	18	
Bone density index (g/cm^3)	Y	1.31	.138	20	--
	O	1.31	.133	18	
Circumference (cm)	Y	7.4	.458	20	--
	O	7.5	.418	18	

*One-tailed t-tests, alpha = 0.05

The mean cortical thickness index values exhibit a similar pattern. Young males have the highest mean (0.064) and older females have the lowest mean (0.043). However, younger females have approximately the same mean (0.054) cortical thickness as do older males (0.053).

The results of the t-tests indicate a significant difference between the younger and older groups for both mean bone mineral (BMI) and cortical thickness (CT/CIRC) for both sexes, as predicted (see Tables 6 and 7). However, there were no significant differences between young and old for bone density (BMI/CT) for either males or females. Younger males have a mean bone density of 1.21 g/cm^3 while older males have a mean of 1.25 g/cm^3. Females have slightly greater mean values for the bone density index: the mean for both the younger and older groups is 1.31 g/cm^3. These results will be discussed in light of the patterns exhibited at the other sites.

These data support the hypothesis that both males and females at the Black Earth site had significantly thinner cortices and, therefore, less bone mineral after midadulthood than did younger individuals. This relationship is reflected by the fact that mean bone density, which is a ratio of the bone mineral index to cortical thickness, does not change significantly after midadulthood.

The next hypothesis concerns sexual dimorphism in the pattern of bone loss at the Black Earth site. It is stated as follows:

HYPOTHESIS 2: Females lose more bone than do males.

In order to evaluate this hypothesis, the percentage changes in the quantity of cortical bone in the younger and older age groups were calculated for each sex. The variables examined were bone mineral index (BMI), bone density (BMI/CT), and cortical thickness index (CT/CIRC). The results indicate that females lose more bone mineral (19% compared with 9%) and cortical thickness (20% compared with 17%) than do males (see Table 8).

TABLE 8.--Percentage Change* After Midadulthood in Black Earth Archaic and Woodland Sample.

Sex	Bone Mineral Index	Cortical Thickness Index	Bone Density Index	Circumference
Males	↓ 9%	↓17%	↑ 3%	↑ 6%
Females	↓19%	↓20%	--	↑ 1%

*Percentage change = $\frac{n_1 - n_2}{n_1} \times 100$

The results of the bone density (BMI/CT) calculations merit some further discussion. Contrary to the prediction that bone density would decrease after midadulthood, the Black Earth sample exhibits a small increase (3%) for males and no change for females. As noted above, there was no statistically significant difference between the means for the younger and older groups for this variable in either sex. These phenomena are important in the overall comparison of the patterns of cortical loss at the three sites, and will be discussed in a later section.

Another sexually dimorphic pattern which emerged from the data was the change in femoral circumference with age. Among males, there is a statistically significant increase in circumference from the younger to the older age groups (Table 6). The increase exhibited by the female sample is slight, and the difference between the means for the younger and older females was not statistically significant (Table 7). This pattern is consistent with Garn's conclusion that males have a greater rate of subperiosteal apposition throughout life than do females (Garn 1970: 19). He suggests that much of this sexual dimorphism can be explained by the accelerated rate, and prolonged duration, of bone growth which males exhibit during adolescence (Garn 1970).

The analysis of cortical bone among males and females at the Black Earth site corroborated Garn's recent observation that those individuals (or populations) that have more cortical bone in young adulthood tend to lose less bone after midadulthood (Garn 1981: 14). This generalization is also relevant to the patterns which have emerged from the comparison of sites, to be discussed in a later section. That is, the hunter-gatherers have denser, thicker bone and lose less bone after midadulthood than do the periodic agriculturalists in this study.

An examination of the changes in the variables by age group was undertaken for the Black Earth site (Tables 9 and 10). Differences in patterns between the sexes were observed. For example, the bone mineral index increases from age group 1 to age group 2 (later young adults, probably in their late twenties) for males, then

TABLE 9.--Descriptive Statistics: Black Earth Males, Archaic and Woodland Combined.

Variable	Age Group 1 (n=7)	2 (n=7)	3 (n=12)	4 (n=7)	5 (n=8)
Bone mineral Index					
Mean (g/cm^2)	.616	.683	.626	.592	.572
s.d.	.056	.133	.061	.074	.096
Cortical thickness index					
Mean	.068	.068	.060	.055	.051
s.d.	.010	.014	.009	.009	.011
Bone density index					
Mean (g/cm^3)	1.163	1.200	1.246	1.239	1.243
s.d.	.129	.137	.132	.085	.130
Circumference					
Mean (cm)	7.9	8.4	8.5	8.7	9.1
s.d.	.613	.340	.443	.559	.515

TABLE 10.--Descriptive Statistics: Black Earth Females, Archaic and Woodland Combined.

Variable	Age Group 1 (n=10)	2 (n=5)	3 (n=5)	4 (n=7)	5 (n=6)
Bone mineral index					
Mean (g/cm^2)	.535	.469	.519	.495	.394
s.d.	.065	.047	.091	.057	.066
Cortical thickness index					
Mean	.058	.046	.054	.050	.040
s.d.	.012	.009	.009	.010	.007
Bone density index					
Mean (g/cm^3)	1.274	1.343	1.335	1.345	1.316
s.d.	.142	.183	.080	.094	.113
Circumference					
Mean (cm)	7.3	7.8	7.2	7.4	7.6
s.d.	.371	.436	.485	.434	.321

steadily declines with age. For females, however, there is a significant decline in bone mineral in the second age group, an increase in the third (early midadulthood), and a decrease thereafter.

One possible explanation for this "dip" among young adult females is the effect of pregnancy and lactation, which are known to affect calcium reserves (Garn 1970). However, Garn reported an unexpected observation that cortical area increases during the first part of pregnancy (due to apposition on the medullary surface), and that parity is associated with a larger cortex in later life. On the other hand, lactation depletes calcium (Retallack et al. 1977; Atkinson and West 1970; Sorenson and Cameron 1967). According to Garn, "In theory, prolonged and repeated lactations lead to premature bone loss" as indicated by cortical thickness or area (Garn 1970: 53). On the other hand, pregnancy without lactation apparently effects a cortical gain (Garn 1970).

These suggestions are corroborated by a more recent study by Goldsmith and Johnston (1975). Estimating bone mineral by photon absorptiometry in 2,135 women, they found that mineralization was positively correlated with parity. Non-lactating parous women, who had had the most children, had the greatest excess of bone mineral compared with a nulliparous group (Goldsmith and Johnston 1975). They also found that postmenopausal women who had lactated had less mineral than nulliparous women. Interestingly, in the group of older postmenopausal white women who had lactated, the bone deficit seemed to be "undergoing repair" (Goldsmith and Johnston 1975: 663). It may be impossible to detect this "repair" in prehistoric populations, because of their shorter average lifespans.

While it is also impossible, in a skeletal population, to determine the parity and lactation history of female specimens, one can assume that most females in "preindustrial" cultures had experienced pregnancy and lactation in early adulthood (see Harrell 1981). Given this assumption and the information provided by research on extant populations, one would expect to find a loss of cortical bone in young adult females in past populations.

In a study of a prehistorical agricultural population from Sudanese Nubia, Martin and Armelagos (1979) reported a bone loss for young adult females, aged 20-29. They attributed this to the demands of pregnancy and lactation during this period as well as to nutritional stress and heavy workloads.

At the Black Earth site, this effect of pregnancy and lactation may be evident in the "dip" at age group 2 in the bone mineral index; a decrease also occurs in the cortical thickness index (see Table 10). However, circumference, by itself, increases in age group 2, among females, followed by a dip in age group 3 and then a steady rise. Bone density follows a similar pattern, with the exception of the late adult group (age group 5). It is interesting to note that bone mineral and cortical thickness decrease overall among females, from age group 1 to 5, while circumference and bone density increase overall.

In general, these findings support the results of Garn's (1970) and Goldsmith and Johnston's (1975) studies with regard to cortical thickness and bone mineral. The contrasting patterns of the circumference and bone density index values suggest that each variable is subject to a unique pattern of change. Garn's study centered on changes evident in cortical thickness and area, and Goldsmith and Johnston's work involved bone mineral analysis, but the additional variables examined in the present study provide slightly different information. Results similar to these were reported in a recent study of cortical structural changes in specimens from Pecos Pueblo, New Mexico (Ruff 1981). Ruff reported that bone density, measured directly from femoral midshaft cores, showed little decrease with advancing age, as is the case at the Black Earth site.

In summary, the data from the Black Earth site support both of the hypotheses proposed at the beginning of this section. With regard to the first hypothesis, males and females have smaller mean bone mineral and cortical thickness index values after midadulthood than before midadulthood. However, mean bone density does not change significantly in either males or females after midadulthood. This phenomenon is a reflection of the relative changes in the bone mineral and cortical thickness values. That is, because cortical thickness decreases as bone mineral decreases, the bone density variable (which is a ratio of the latter to the former) exhibits little change. There is a small increase (3%) for males and no change for females in the mean bone density index after midadulthood.

The data from the Black Earth site also support the second hypothesis, that females lose more bone than do males. This is exhibited in terms of the greater percentage loss, after midadulthood, of bone mineral and cortical thickness among females than among males.

Changes in these variables were also examined by age group. It was suggested that parity and lactation may account for some of the sexual dimorphism observed in the patterning of cortical loss. Cortical expansion with advancing age was also noted and discussed.

Dickson Mounds, Larson Phase

The Dickson Mounds sample consists of 28 males. For purposes of the intrasite analysis, the sample was divided into "young" and "old" categories, which consisted of age groups 1, 2, and 3; and 4 and 5, respectively. Fourteen individuals comprise each group.

The first hypothesis to be tested is as follows:

HYPOTHESIS 1: Mean bone mineral (BMI), cortical thickness (CT/CIRC), and bone density (BMI/CT) will be lower in individuals past midadulthood than in early adulthood.

In order to test this hypothesis, one-tailed t-tests were performed, with alpha set at 0.05. None of the tests were significant (Table 11). This was not unexpected, given the small sizes of the samples. The relationship between power (the ability to detect a significant difference between means) and sample size is such that the smaller the samples are, the smaller the power of the test will be (Hays 1973: 360-362). Since it is impossible, in this case, to increase the sample sizes from Dickson Mounds and Fletcher, two alternative approaches to evaluating Hypothesis 1 will be taken.

The first alternative examines the percentage change in the variables from younger to later adulthood. This proved to be a

TABLE 11.--T-Tests: Comparison of Younger (Y) and Older (O) Age Groups Among Dickson Mounds Males.

Variable (units)	Age	Mean	s.d.	N	Significance*
Bone mineral index (g/cm^2)	Y	.51	.089	14	--
	O	.46	.097	14	
Cortical thickness index	Y	.055	.009	14	--
	O	.052	.010	14	
Bone density index (g/cm^3)	Y	1.02	.106	14	--
	O	0.97	.149	14	
Circumference (cm)	Y	9.1	.608	14	--
	O	9.2	.627	14	

*One-tailed t-tests, alpha = 0.05

valuable method. The results indicate that there is a decline in bone mineral (10%) cortical thickness (5%), and bone density (5%) after midadulthood (Table 12). These results support the hypothesis proposed above. The magnitude of the changes will be discussed in a later section of this chapter, in which the three sites are compared.

TABLE 12.--Percentage Change* After Midadulthood.

Sample	Bone Mineral Index	Cortical Thickness Index	Bone Density Index	Circumference
Black Earth Archaic, males	↓ 8%	↓16%	↑ 2%	↑6%
Black Earth Archaic, females	↓10%	↓16%	↑ 5%	↑1%
Dickson Mounds Males	↓10%	↓ 5%	↓ 5%	↑1%
Fletcher, Females	↓18%	↓ 7%	↓18%	↑8%

*Percentage change = $\frac{n_1 - n_2}{n_1} \times 100$

Changes in the femoral circumference with age were also examined with this method. While the percentage change from the younger to the older group was only an increase of 1% (Table 12), the increase from the mean of age group 1 to age group 5 was 5% (Table 13). There is an increase of 8% from age group 1 to age group 2; that is, among young adult males. This pattern is consistent with

TABLE 13.--Descriptive Statistics: Dickson Mounds (Larson Phase), Circumference.

	Age Group				
Statistics	1 (n=3)	2 (n=4)	3 (n=7)	4 (n=4)	5 (n=10)
Mean	8.8	9.5	9.0	9.0	9.2
s.d.	.700	.759	.410	.457	.690

Garn's findings, which were discussed in the previous section (Garn 1970).

The second alternative approach involves the conversion of the data to nominal-level data in order to employ Fisher's Exact test for small samples. Fisher's Exact test, which uses contingency tables, yields the probability that exactly those frequencies observed in a given sample would be obtained if there were no differences between the population proportions (Blalock 1979). Blalock recommends the test for samples in which the number of cases in a cell is very small, but cautions that the degree of relationship must be very high in order to detect a significant difference between the samples (Blalock 1979: 321). That is, Fisher's Exact test is very conservative with respect to rejecting the null hypothesis that there are no differences in the population proportions.

In order to partition the data for the bone mineral, cortical thickness,and bone density indices into two categoreis, the median value was determined for each variable. Therefore, each category contained half the sample, and the distribution of "young" and "old" in these categories was determined. The probability obtained with Fisher's Exact test for the bone mineral index was 0.13, and for bone density index the probability was 0.35 (Tables 14 and 15). For cortical thickness index the cells contained an equal number of cases and the test was not performed.

TABLE 14.--Fisher's Exact Test for Differences Between the Younger and Older Groups at Dickson Mounds: Bone Mineral Index.

Bone Mineral Index (g/cm^2)	Younger	Older	p
$\leq .459$	5	9	0.13
$>.459$	9	5	

TABLE 15.--Fisher's Exact Test for Differences Between the Younger and Older Groups at Dickson Mounds: Bone Density Index

Bone Density Index (g/cm^2)	Younger	Older	p
≤ 1.01	6	8	0.35
> 1.01	8	6	

Given the conservative nature of the test, the results indicate that there is a significant difference between young and old for bone mineral index ($p = 0.13$), which supports the above hypothesis.

However, the hypothesis is not supported by the test results for either the bone density or the cortical thickness index. Although these findings appeared, at first, to contradict the general model proposed for bone loss, a comparison of the relative changes in the three variables at the three sites does support the model. One trend that is noted in a later section of this chapter (in which the three sites are compared) is that while bone mineral decreases significantly after midadulthood in the Dickson Mounds and Fletcher samples, cortical thickness does not decrease proportionately. The result is a net loss of bone density (Table 12). Therefore, the results of the Fisher's Exact test for these variables are consistent with the model which emerges from the comparison of cortical bone changes in hunter-gatherers and agriculturalists.

In summary, the Dickson Mounds data generally support the hypothesis that adults (males), after midadulthood, have less bone mineral than do younger adult males. There is no significant difference in bone density or cortical thickness between the young and old groups, but there is a 5% decrease in the mean values after midadulthood. The data also indicate that there is a slight increase in femoral circumference with advancing age.

The Fletcher Site

Because of the poor condition which characterizes much of the Fletcher skeletal collection, only a small sample of femoral cortices was obtained. Fourteen females were sampled; of these, three were eliminated because age was indeterminable. Seven males were sampled, but statistical analysis was impossible on such a small sample, especially when the sample was further divided into younger and older categories. Therefore, only the females are included in the present study, and with some reservations about the very small sample sizes. With these limitations in mind, general patterns will be examined.

The following hypothesis was evaluated:

HYPOTHESIS 1: Mean bone mineral (BMI), cortical thickness (CT/CIRC), and bone density (BMI/CT) will be lower in individuals past midadulthood than in early adulthood.

One-tailed t-tests were performed, with alpha set at 0.05. Two of the three tests showed no significant difference between means (Table 16). The one significant difference between means was for bone density, and supports the proposed hypothesis for this variable.

Because of the problem with small sample sizes (discussed in the previous section), the hypothesis was evaluated with the alternative methods that were employed for the Dickson Mounds data. The percentage changes with age were examined for the three variables. As before, the sample was subdivided into "younger" (age groups 1, 2, and 3) and "older" (age groups 4 and 5) categories. The percentage changes, all of which are declines, are presented in Table 12. The percentage decline in the bone mineral and bone density indices is 18%, and the decline in the cortical thickness index is 7%. These data support the hypothesis proposed above. The significance of the magnitude of these changes will be evaluated in light of the data from the other sites, in the next section of this chapter.

TABLE 16.--T-Tests: Comparison of Younger (Y) and Older (O) Age Groups Among Fletcher Females.

Variable (units)	Age	Mean	s.d.	N	Significance*
Bone mineral index (g/cm^2)	Y	.36	.070	7	--
	O	.30	.075	4	
Cortical thickness index	Y	.042	.008	7	--
	O	.039	.008	4	
Bone density index (g/cm^3)	Y	1.10	.177	7	*
	O	.90	.115	4	
Circumference (cm)	Y	7.9	.993	7	--
	O	8.5	.594	4	

*One-tailed t-tests, alpha = 0.05

There is an increase in the femoral circumference after midadulthood, which is consistent with the results from the other sites and with Garn's (1970) observations (see Tables 12 and 16). It was not feasible to examine changes in circumference in the five age groups because of the small sample size from Fletcher. It is sufficient to mention that there is an overall increase from the youngest to the oldest age group: the mean circumference of age group 1 was 7.6 cm. (s.d. = .153), and for age group 5 it was 8.4 cm. (s.d. = .651). Both groups contained only three individuals.

The significance of the differences in these variables between young and old were evaluated with the Fisher's Exact test. Each variable was partitioned at the median, and the probability that the observed frequencies would be obtained if there were no differences in the population proportions was calculated. The probabilities for the bone mineral and the bone density index were both 0.05 (Tables 17 and 18). These results indicate that the differences between the young and old groups are significant for these variables, and they support the above hypothesis. The test was impossible to perform for the cortical thickness index because of the distribution of the data in the cells of the contingency table. That is, the proportions were not consistent with the hypothesis that cortical thickness is lower in individuals after midadulthood. As was previously discussed, this apparent enigma is resolved somewhat in the next section's comparison of the relative changes in the variables. These data are consistent with the proposition that the agriculturalists lose proportionately

TABLE 17.--Fisher's Exact Test for Differences Between the Younger and Older Groups at the Fletcher Site: Bone Mineral Index.

Bone Mineral Index (g/cm^2)	Younger	Older	p
≤ .355	2	4	0.05
> .355	5	0	

TABLE 18.--Fisher's Exact Test for Differences Between the Younger and Older Groups at the Fletcher Site: Bone Density Index.

Bone Density Index (g/cm^2)	Younger	Older	p
≤ 1.05	2	4	0.05
> 1.05	5	0	

more bone mineral than cortical thickness and, therefore, exhibit a net loss of bone density.

In summary, the data from the Fletcher sample of females support the hypothesis that individuals past midadulthood exhibit a loss of bone mineral and bone density. While there is a 7% decrease in mean cortical thickness after midadulthood, there is no significant decrease in cortical thickness in Fletcher females after midadulthood. The data also indicate that femoral circumference increases with advancing age.

The remainder of this chapter is concerned with comparisons between the three sites. The population differences will be evaluated in light of the contrasting subsistence strategies represented at the sites.

Comparisons Between Sites

The first two hypotheses to be evaluated concern the proposed differences in the quantity of cortical bone in individuals from the sites. It is suggested that the hunter-gatherers from the Black Earth site will have significantly different amounts and patterns of loss of cortical bone when compared to the agriculturalists from Dickson Mounds and Fletcher. As discussed in Chapter II, anthropological studies have indicated that hunter-gatherers lose less bone than do agriculturalists. This proposition will be addressed in this section.

In order to test the hypotheses, the samples were again subdivided into "young" and "old," consisting of age group 1, 2, and 3; and 4 and 5, respectively. The younger and older groups were examined separately in an effort to minimize discrepancies in the age distributions, as age is known to have a significant influence on cortical growth and loss. The sexes will be treated separately, also.

The first two hypotheses are stated as follows:

HYPOTHESIS 3: The female samples (younger and older) from the Black Earth site will have mean values for bone mineral (BMI), cortical thickness (CT/CIRC), and bone density (BMI/CT) which are significantly different from those of the females from Fletcher.

HYPOTHESIS 4: The male samples (younger and older) from the Black Earth site will have mean values for bone mineral (BMI), cortical thickness (CT/CIRC), and bone density (BMI/CT) which are significantly different from those of the males from Dickson Mounds.

In order to test these hypotheses, two-tailed t-tests were performed, with alpha set at 0.05 (see Tables 19 through 22). The results indicate that there is a significant difference in mean bone mineral and mean bone density between all of the pairs of samples which were compared. That is, the differences were significant for both younger and older males from Black Earth and Dickson Mounds, and for both younger and older females from Black Earth and Fletcher. In all cases, the Black Earth samples exhibited greater bone mineral and greater bone density than either Dickson Mounds or Fletcher. The tests for cortical thickness (CT/CIRC) were significant only for younger males and younger females, and in both cases the Black Earth samples had greater mean cortical thickness.

In general, then, the data support the hypotheses that the mean values for bone mineral, cortical thickness, and bone density are significantly different at the three sites. In each case, the Black Earth samples exhibit greater mean values than do either Fletcher or Dickson Mounds.

The last two hypotheses deal with differences in the patterns of cortical loss between the populations. The hypotheses are stated as follows:

HYPOTHESIS 5: The pattern of cortical loss among males will be different in the two populations, Black Earth and Dickson Mounds.

TABLE 19.--T-Tests: Comparisons Between Black Earth (BE) and Dickson Mounds (DM), Younger Males.

Variable	Sample	Mean	s.d.	N	Significance*
Bone mineral index (g/cm^2)	BE	.63	.090	21	*
	DM	.51	.089	14	
Cortical thickness index	BE	.063	.011	21	*
	DM	.055	.009	14	
Bone density index (g/cm^3)	BE	1.22	.126	21	*
	DM	1.02	.106	14	
Circumference (cm)	BE	8.4	.511	21	*
	DM	9.1	.608	14	

*Two-tailed t-tests, alpha = 0.05

TABLE 20.--T-Tests: Comparisons Between Black Earth (BE) and Dickson Mounds (DM), Older Males.

Variable	Sample	Mean	s.d.	N	Significance*
Bone mineral index (g/cm^2)	BE	.58	.084	15	*
	DM	.46	.097	14	
Cortical thickness index	BE	.053	.010	15	--
	DM	.052	.010	14	
Bone density index (g/cm^3)	BE	1.24	.108	15	*
	DM	0.97	.149	14	
Circumference (cm)	BE	8.9	.544	15	--
	DM	9.2	.627	14	

*Two-tailed t-tests, alpha = 0.05

TABLE 21.--T-Tests: Comparisons Between Black Earth (BE) and Fletcher (F), Younger Females.

Variable	Sample	Mean	s.d.	N	Significance*
Bone mineral index (g/cm^2)	BE	.51	.076	13	*
	F	.36	.070	7	
Cortical thickness index	BE	.055	.012	13	*
	F	.042	.008	7	
Bone density index (g/cm^3)	BE	1.28	.111	13	*
	F	1.10	.177	7	
Circumference (cm)	BE	7.4	.471	13	--
	F	7.9	.993	7	

*TwO-tailed t-tests, alpha = 0.05

TABLE 22.--T-Tests: Comparisons Between Black Earth (BE) and Fletcher (F), Older Females.

Variable	Sample	Mean	s.d.	N	Significance*
Bone mineral index (g/cm^2)	BE	.46	.072	12	*
	F	.30	.075	4	
Cortical thickness index	BE	.046	.010	12	--
	F	.039	.008	4	
Bone density index (g/cm^3)	BE	1.34	.094	12	*
	F	0.90	.115	4	
Circumference (cm)	BE	7.5	.388	12	*
	F	8.5	.594	4	

*Two-tailed t-tests, alpha = 0.05

HYPOTHESIS 6: The pattern of cortical loss among females will be different in the two populations, Black Earth and Fletcher.

The specific patterns which will be examined are the amount, timing and relative changes in the variables bone mineral, cortical thickness, and bone density index. The following analyses are expected to reveal consistent differences in these patterns: graphic representations of the data with respect to the means of the three variables in each age group; and, data concerning the percentage of bone lost after midadulthood. The latter source of information was discussed for each site separately in the preceding sections, but will be used to compare the sites in this section.

Figures 7 through 12 illustrate the mean bone mineral (BMI), cortical thickness (CT/CIRC), and bone density (BMI/CT) values for each age group in each population. Males and females are treated separately.

The graphs illustrate that, with two exceptions, the means for all three variables are consistently greater among the hunting-gathering group (Black Earth males and females) than among the agriculturalists (Dickson Mounds males and Fletcher females). That is, in all five age groups, Black Earth males and females have more bone mineral, thicker cortices, and denser bone than do the corresponding samples from Dickson Mounds and Fletcher. The two exceptions to this pattern are, first, that cortical thickness is smaller among Black Earth males in age group 4; and, second, that bone density is slightly lower for Black Earth females in age group 1. Sampling error may be responsible for this apparent enigma, since there are no other

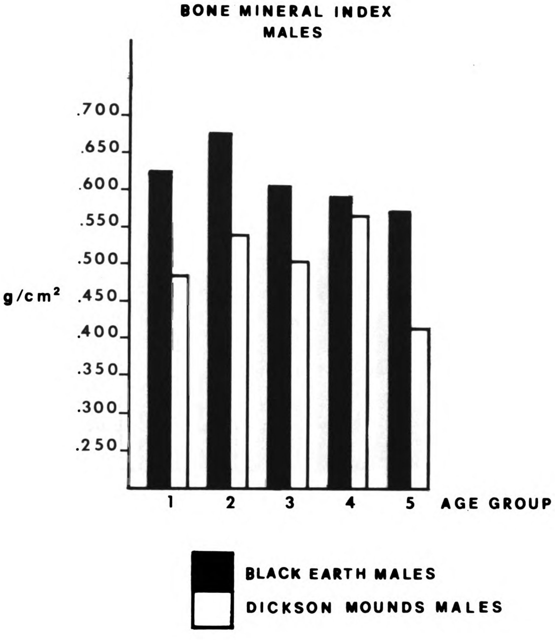

Figure 7.--Mean bone mineral index, for each age group, among males.

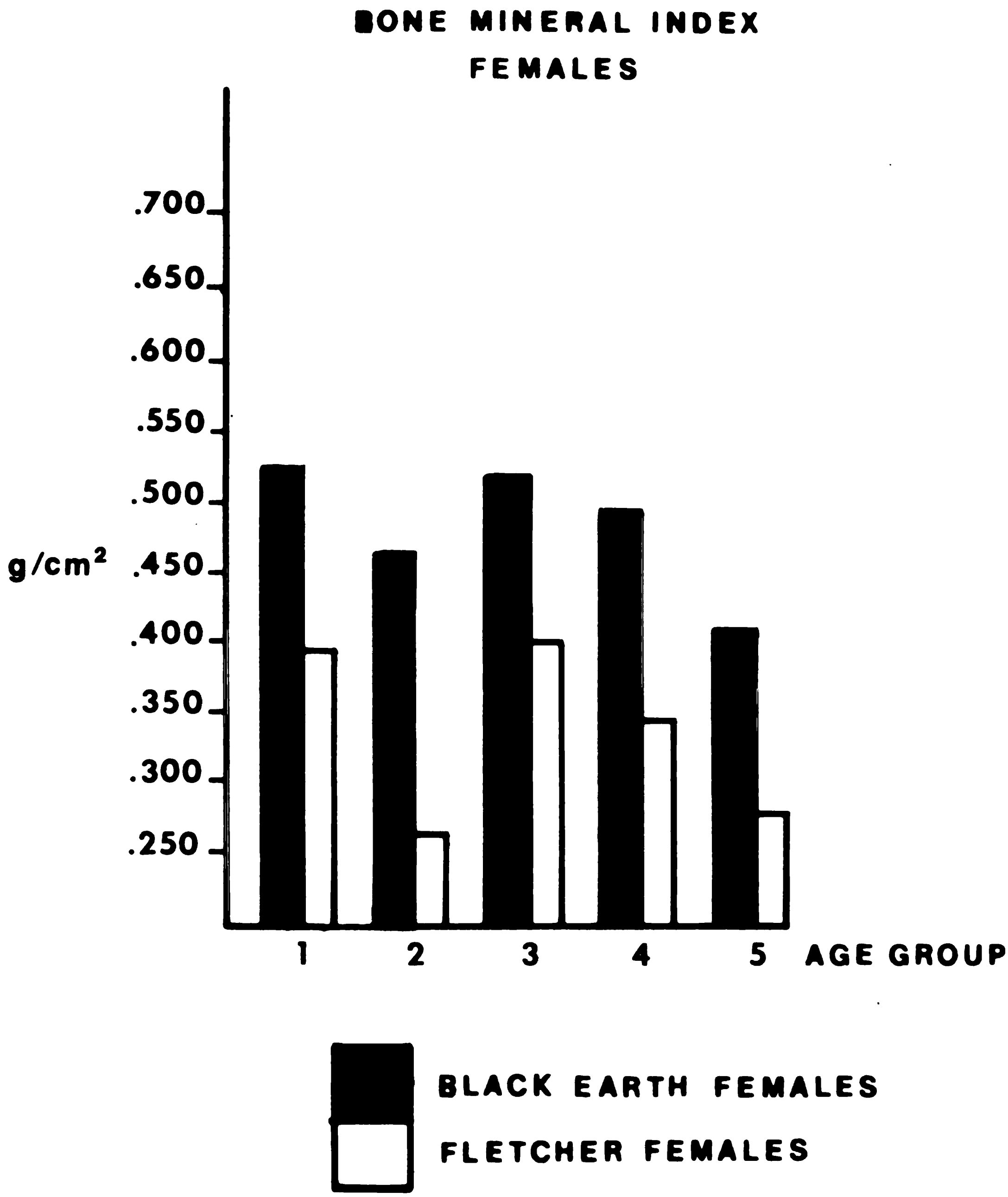

Figure 8.--Mean bone mineral index, for each age group, among females.

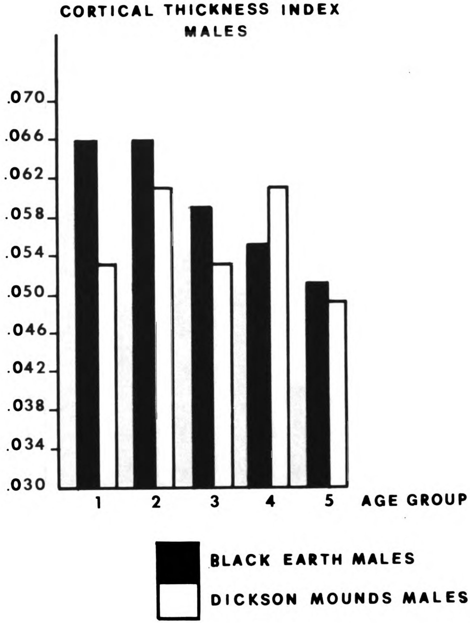

Figure 9.--Mean cortical thickness index, for each age group, among males.

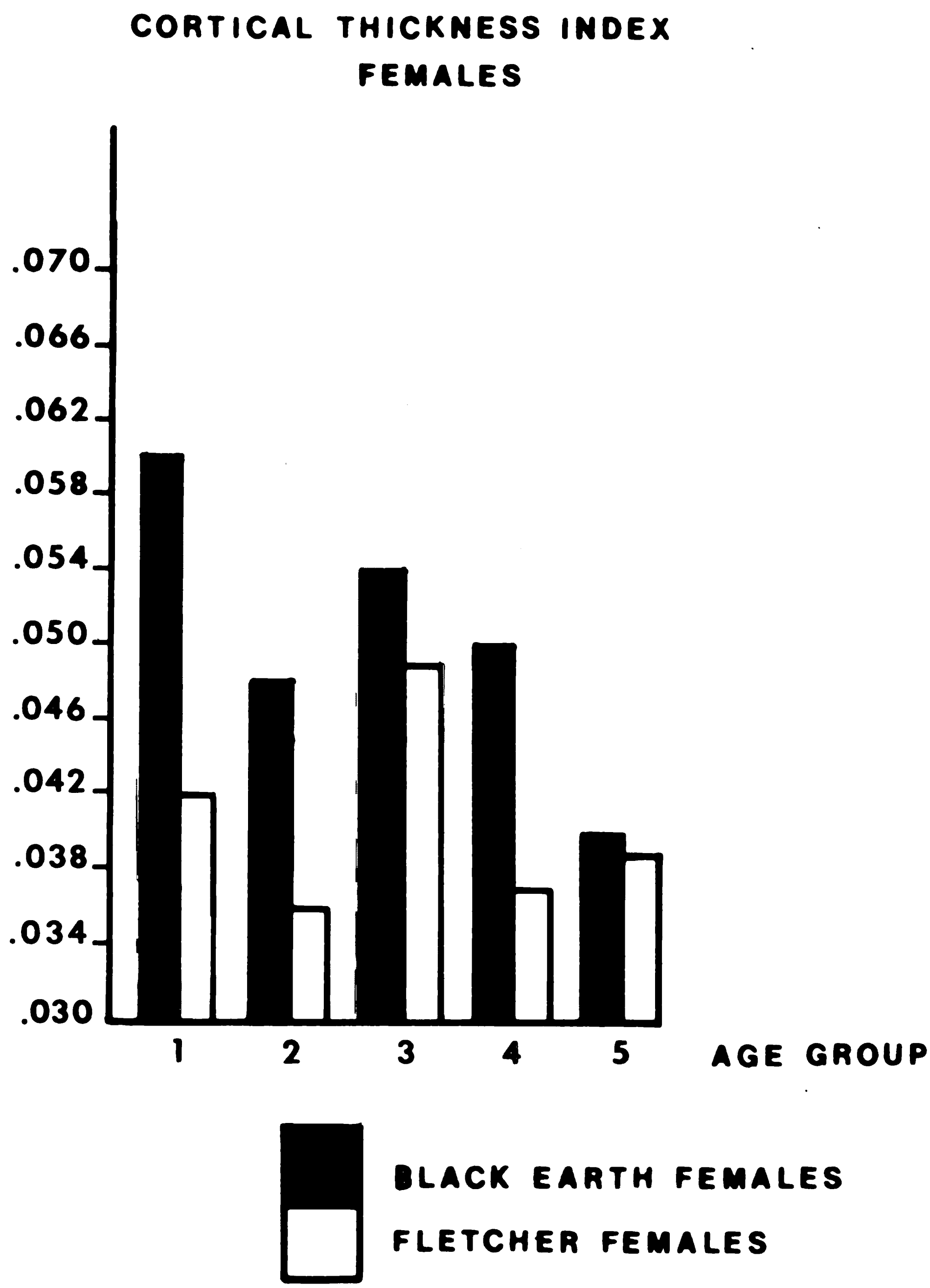

Figure 10.--Mean cortical thickness index, for each age group, among females.

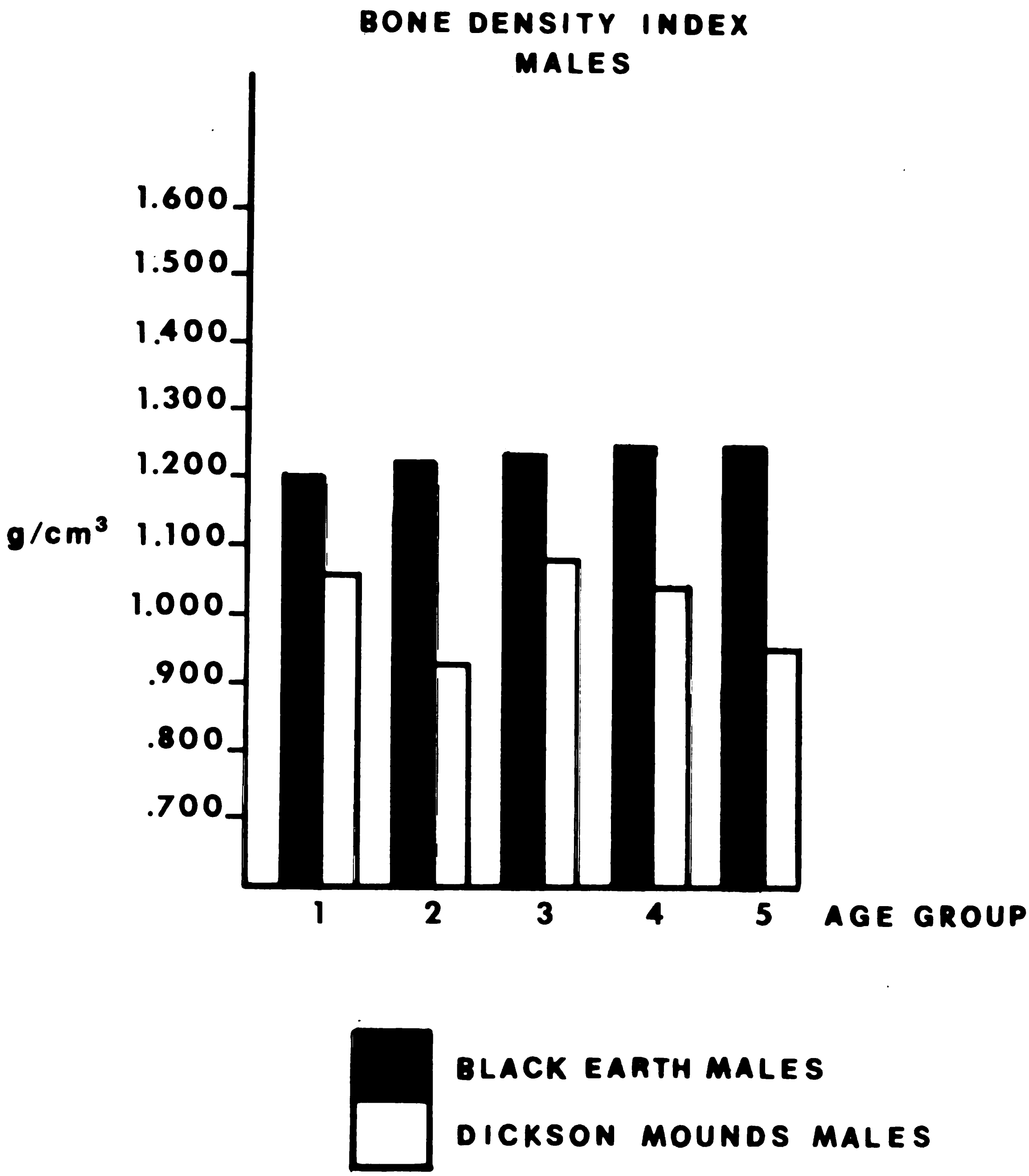

Figure 11.--Mean bone density index, for each age group, among males.

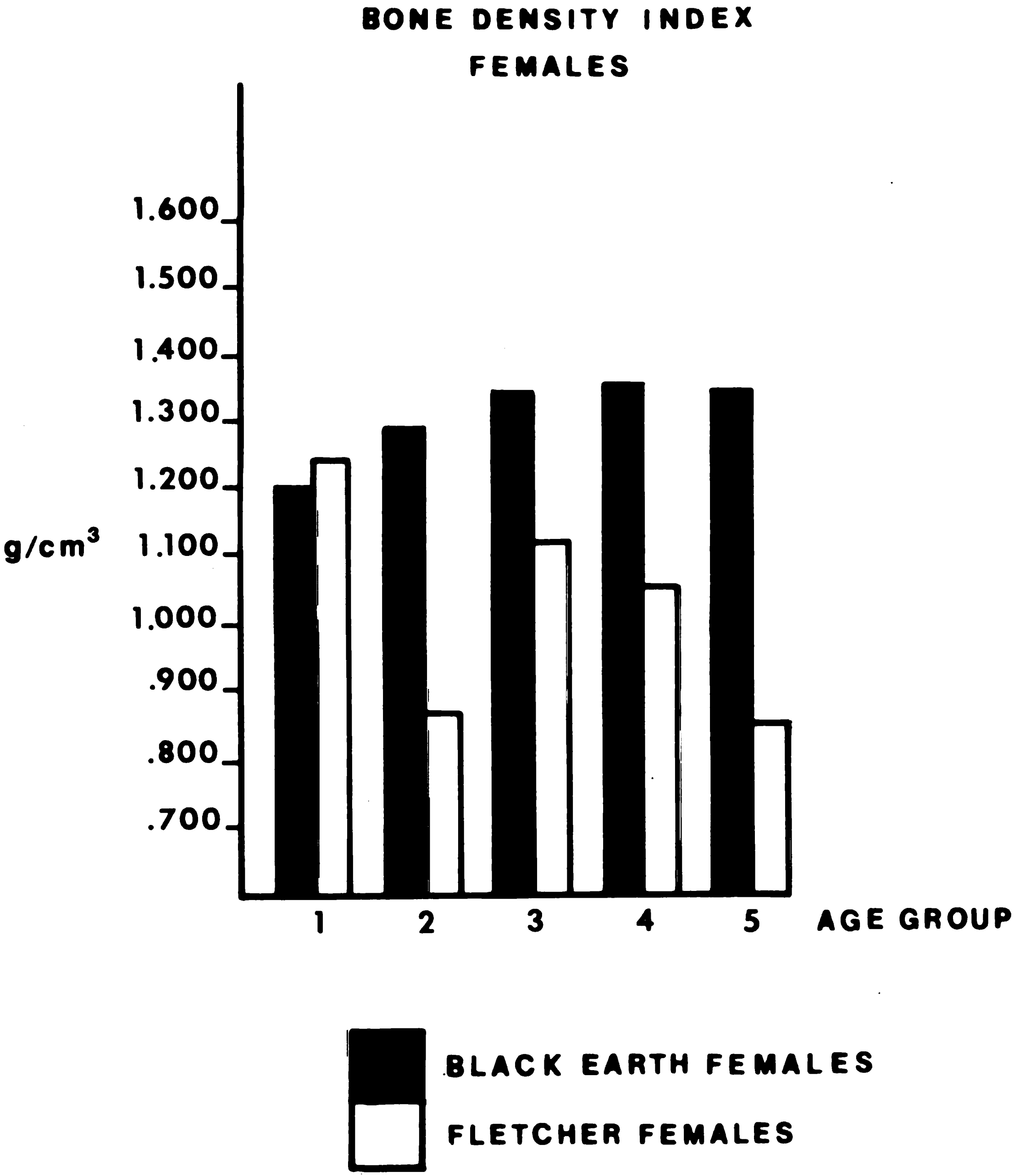

Figure 12.--Mean bone density index, for each age group, among females.

systematic differences associated with it. The small sample sizes of each age group precluded tests for significant differences between the means.

It is significant that consistent, patterned differences emerged from these data. As was discussed in Chapter II, previous anthropological research has indicated that hunter-gatherers have more cortical bone than do agriculturalists. The results of the present study support this proposition. That is, the hunter-gatherers in this study have denser, thicker bone, in every age group, than do the agriculturalists (with the exceptions noted above).

The hypotheses stated above are supported by the graphic analysis of the data. Next, the pattern of bone loss after midadulthood will be examined, using the percentage change data for bone mineral (BMI), cortical thickness (CT/CIRC), and bone density (BMI/CT). For this part of the analysis, the samples were divided into the "young" and "old" categories described previously. Table 12 illustrated the percentage changes after midadulthood in each of the variables at the three sites. Three important facets of these changes are the magnitude and the direction of the changes, and the relationship between the three variables.

In terms of the magnitude of the changes, Dickson Mounds males and Fletcher females lose more bone mineral than do Black Earth males and females. Dickson Mounds males show a loss of 10% compared with 8% among Black Earth males, and Fletcher females lose 18% of their bone mineral after midadulthood compared with 10% for Black Earth females. This pattern is reversed for cortical thickness, with

Black Earth males losing more (16%) than Dickson Mounds males (5%); and Black Earth females losing 16% compared with 7% for Fletcher females.

This apparent enigma may be better understood in terms of the changes which occur in the bone density index. For this variable, Dickson Mounds males show a percentage decrease of 5%; Fletcher females show a loss of 18%. At the Black Earth site, however, the males had a 2% increase, and the females a 5% increase, in bone density after midadulthood. As discussed in Chapter V, the relationship between the bone mineral index, cortical thickness,[6] and the bone density index is as follows:

$$\text{bone density index (g/cm}^3\text{)} = \frac{\text{bone mineral index (g/cm}^2\text{)}}{\text{cortical thickness (cm)}}$$

As in any ratio, the value of the fraction can be decreased in two ways--by increasing the denominator or by decreasing the numerator. In terms of the bone density index, it will decrease after midadulthood if the loss of bone mineral (numerator) is greater relative to the loss of cortical thickness (denominator). This is the case among the Dickson Mounds and Fletcher samples. That is, they apparently lose more bone mineral than cortical thickness after midadulthood, resulting in a significant loss of bone density. The opposite is true for the Black Earth males and females: they lose more cortical thickness than they do bone mineral, resulting in a slight increase

[6]For this part of the discussion, cortical thickness is the direct measurement taken on each sample, not divided by circumference (see Chapter V).

in bone density after midadulthood. Figure 13 illustrates the two different patterns schematically.

In summary, the patterns of cortical loss are clearly different for the hunter-gatheres and agriculturalists in this study. Graphic representations of changes in the means for the variables in each age group support this proposition, as do the analyses of the percentage changes in bone mineral, cortical thickness, and bone density after midadulthood. Furthermore, these results support the proposition that hunter-gatherers have denser, thicker bone, and lose less bone after midadulthood, than do agriculturalists.

Discussion

One final relationship, between the three cortical values and femoral circumference, most be noted. When the samples are subdivided into younger and older males and females, and the sites are compared on this basis, then an interesting relationship emerges. The mean femoral circumference is between 3% and 13% higher for Dickson Mounds and Fletcher than for the corresponding samples from Black Earth (Tables 19 through 22). Only two of the differences are significant at the 0.05 level, as indicated. Despite the greater circumference values, the Dickson Mounds and Fletcher samples have consistently lower values for bone mineral, cortical thickness, and bone density (Tables 19-22). It is possible that the greater circumference is an adaptation, in a biomechanical sense, to having less bone mineral and thinner cortices. Another explanation would be that the greater circumference indicates a difference in body size, but there was no

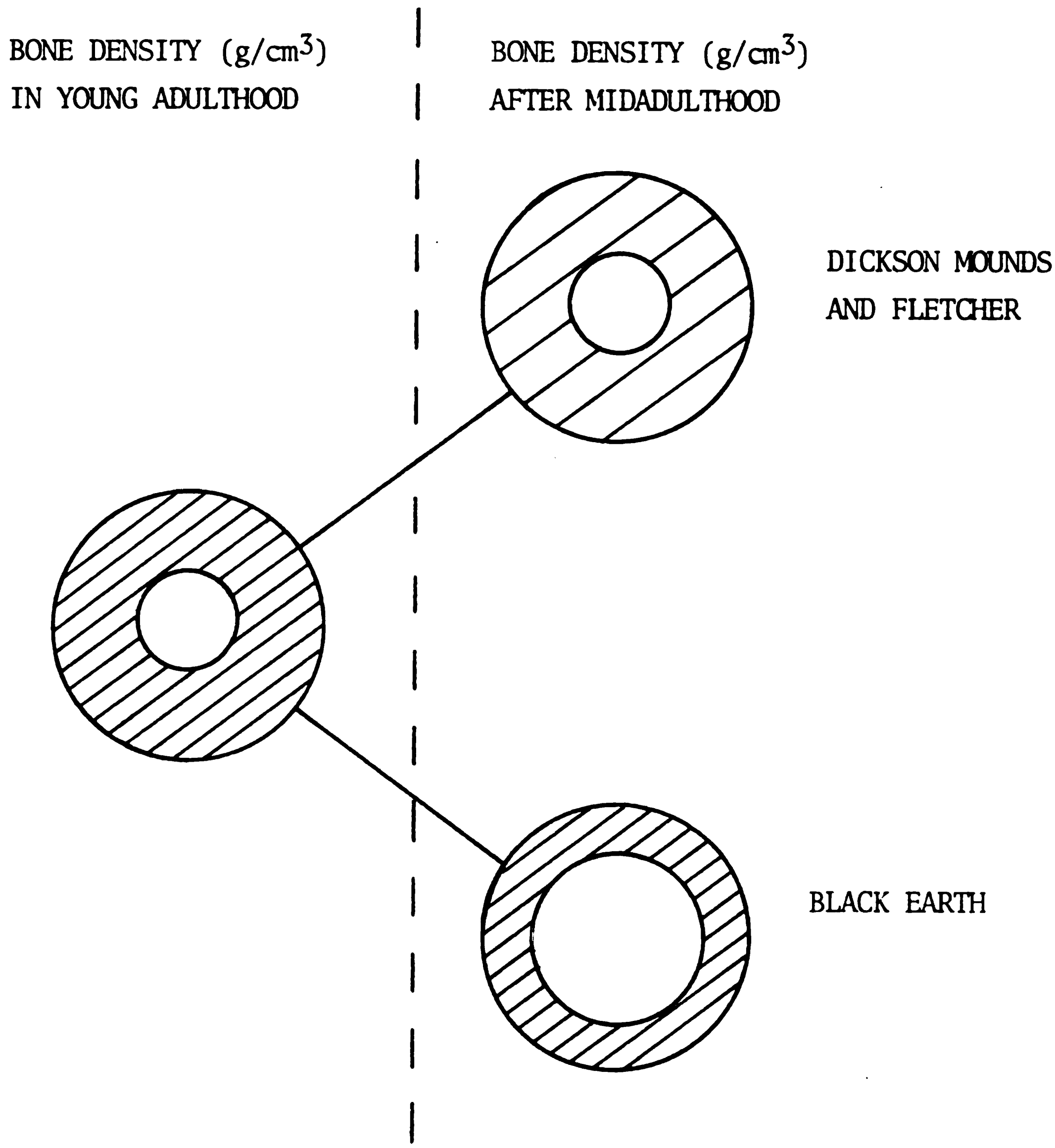

Figure 13.--Difference in pattern of cortical bone loss among hunter-gatherers (Black Earth) and agriculturalists (Fletcher and Dickson Mounds).

significant difference in femoral length for males from the sites (see beginning of this chapter). This proposition, based on the notion of biomechanical adaptation, is also supported by the fact that at each site the circumference increases with advancing age even as bone mineral and cortical thickness decrease. It may be recalled that Garn (1970) reported a similar increase in circumference with advancing age, and a corresponding bone loss after midadulthood.

The results of a study by Carlson, Armelagos, and VanGerven (1976) support the proposition that circumferential expansion in the femur may be, at least in part, a biomechanical adaptation to cortical loss. After analyzing 40 femora from the Campbell site, Missouri, they concluded that the observed increase in femoral diameter seemed to be a compensation for bone loss at the endosteal surface. In the femur, which is a weight-bearing bone, this may be influenced by mechanical stresses (Carlson et al. 1976; Smith and Walker 1964). However, since Garn et al. (1967) found that cortical expansion occurs similarly in the second metacarpal, it is not simply a biomechanical response. Carlson et al. conclude that the combination of cortical expansion and endosteal resorption help to "reduce the loss of overall bone mass" (Carlson et al. 1976: 309). This conclusion is supported by the Black Earth data, which suggest that while bone mineral and cortical thickness decrease after midadulthood, bone density and circumference increase.

It was also noted that there were sex differences in the amount of circumferential expansion in the Black Earth site. Males exhibited a larger increase after midadulthood than did females. Carlson et al. (1976) noted a similar sex difference in their sample. In a more recent study, Martin and Atkinson (1977) observed a sex difference in another, related femoral variable in data obtained from four sites. They found that "the increased bone porosity of old age was compensated by an increased structural strength," but only in males (Martin and Atkinson 1977: 229). They suggest that this change may be a biomechanical compensation but, if so, the sex difference is enigmatic. In summary, the results of this and related studies indicate that the expansion of the cortex in the femur with advancing age is a compensation, partly biomechanical, for bone loss.

Summary

In general, the results of both the intra- and inter-site analyses supported the hypotheses proposed in Chapter IV. Furthermore, the data indicated that the hunter-gatherers (Black Earth) in this study had denser, thicker bone and lost less bone after midadulthood than did the agriculturalists (Dickson Mounds and Fletcher). These observations support the results of similar anthropological studies of past populations.

Several interesting patterns of cortical change were noted. One is that femoral circumference increases with advancing age in all three populations, but especially among males. Also, when the younger and older groups from each site are compared, the Dickson Mounds and Fletcher samples have consistently greater mean circumference values. It was suggested that expansion in the circumference of the femur might be a biomechanical adaptation to cortical loss.

Another interesting pattern which was discussed is the sexually dimorphic trend in the bone mineral index. That is, bone mineral index increases among early adult males but decreases among early adult females. It was suggested that pregnancy and lactation might be factors in this pattern.

Finally, the most significant pattern which the analysis revealed involves changes in the bone density index after midadulthood. While bone density decreases markedly in the Dickson Mounds and Fletcher samples, it increases slightly in the Black Earth samples. This difference can be explained, at least in part, by the relative changes in the components of the bone density index. Specifically, in the Black Earth sample cortical thickness declines more than does bone mineral after midadulthood, resulting in a slight increase in the bone density index. Conversely, in the Dickson Mounds and Fletcher samples, bone mineral declines more than cortical thickness after midadulthood, resulting in a significant decrease in bone density.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Summary

Studies have shown that age-related cortical bone loss is a universal phenomenon, but that there are individual and population-level variations in the severity of the loss. That is, some individuals and some populations suffer a greater bone deficit with advancing age than do others (Garn 1970). This variation in cortical loss is relatd to variations in diet, activity level, hormonal state, and genetic constitution (Parfitt 1983). The present study focuses on the relationship between subsistence (dietary) differences and differences in bone loss after midadulthood in three archaeological populations.

These populations represent two different subsistence economies, hunting-gathering and maize agriculture. The hunting-gathering sample is from the Black Earth site, Illinois, and the agricultural populations are from Dickson Mounds, Illinois, and the Fletcher site, Michigan. It was proposed that the hunter-gatherers in this study would have denser, thicker bone before and after midadulthood than would the corresponding age groups from the agricultural samples. It was also proposed that the agriculturalists would lose more bone after midadulthood than would the hunter-gatherers.

These hypotheses were tested with data that were collected, by the author, from the femora of a total of 123 individuals from the three sites. Femoral cortical samples were excised from each specimen, and from these samples were obtained measurements of the bone mineral content, cortical thickness, and a new index of bone density. Whole-bone measurements and age and sex data were also obtained. The results of the analysis supported the hypotheses concerning the population differences.

Intrasite (age and sex) variation was also examined for each population. The results of these analyses supported hypotheses that stated that females would exhibit greater cortical loss than would males; and, that adults past midadulthood, at all three sites, would exhibit a decrease in cortical bone. These hypotheses, as well as the ones concerning differences between the sites, were formulated from the cumulative findings of recent medical and anthropological research (Dewey et al. 1969; Garn 1970; Armelagos et al. 1972; Perzigian 1973; Van Gerven 1973; Mazess and Mather 1974 and 1975; Carlson et al. 1976; Ericksen 1976 and 1979; Richman et al. 1979; Martin and Armelagos 1979; Thompson and Guiness-Hey 1981; Mazess and Christiansen 1982; Pfeiffer and King 1983).

The results of these and other studies, which were reviewed in Chapter II, indicated that the diet of maize agriculturalists may have had adverse effects on the developing and adult skeleton. These effects are reflected in the severity of age-related cortical loss observed among the maize agriculturalists from Dickson Mounds and Fletcher, especially in comparison with the Black Earth sample. Some of the undesirable nutritional factors in a maize-based diet are the high phosphorus/low calcium ratio; the low protein content; and the presence of chelating agents (Gilbert 1975; Pfeiffer and King 1983). Other relevant aspects of an agricultural economy include an increase in infectious disease, which interacts synergistically with poor nutrition, and periods of low food intake or starvation (Mensforth et al. 1978; Richman et al. 1979). In summary, nutritional stress characterized many prehistoric maize agriculturalists (see Buikstra and Cook 1980).

Medical and anthropological research has suggested that factors which affect the growing skeleton may ultimately affect the adult skeleton (e.g. Parfitt 1983). Therefore, as Garn phrased it, "the best protection against adult bone loss is a more massive skeleton to start with" (Garn 1982: 14). This proposition is illustrated by the results of the inter-population comparison in the present study. That is, the hunter-gatherers had more cortical bone (in terms of bone mineral, cortical thickness, and bone density) in young adulthood than did either agricultural group. As was discussed in Chapter VI, there was no apparent difference in body size, between Black Earth and Dickson Mounds, that might explain the difference in bone mass. The results of this study suggest that differences in the gain and loss of cortical bone are related to differences in subsistence between the sites.

Discussion

One significant trend which was noted during the course of this study was a decrease in bone mineral among young adult (age group 2) females at the Black Earth site. This decrease may reflect a loss of bone mineral that is associated with lactation (Garn 1970; Goldsmith and Johnston 1975).

Another variable that was examined was femoral circumference which increased, overall, with advancing age in all three populations. One interesting relationship among the sites with regard to this variable is that the agriculturalists have higher mean values than do the hunter-gatherers. It was suggested that the greater circumference may be a biomechanical adaptation to the lower bone density observed among older adults at the agricultural sites.

Two characteristics of the present study distinguish it from most of the other studies that were cited in earlier chapters. First, the hypotheses were formulated specifically to predict differences in cortical loss among populations that had different subsistence bases, i.e., dietary regimes. Ruff et al. (1984) represents a similar attempt to study the effect on cortical bone of levels of physical activity in pre- and post-agricultural populations. The problems with this study are discussed in Chapter II. Other studies compared diverse populations and suggested several explanations for the differences (e.g. Ericksen 1976). In one study, however, Richman et al. (1979) focused on dietary differences between the Arikara, Pueblo, and Eskimo.

The other significant characteristic of the present study is the use of a new index, the bone density index, which is the ratio of bone mineral to cortical thickness (measured directly on each sample). The analysis of the concomitant changes in all three variables after midadulthood clarified the differences in cortical loss among hunter-gatherers and agriculturalists. Perhaps the most significant conclusion of this study is the following: the hunter-gatherers lost proportionately more cortical thickness than bone mineral, so that bone density does not decrease after midadulthood as it does among the agriculturalists at Dickson Mounds and Fletcher. At the latter two sites, the decrease in bone mineral is greater than the cortical thinning, so that bone density does decrease. The result is a decrease in bone mass after midadulthood among the agriculturalists, which might be characterized as osteoporosis.

Osteoporosis, which is considered to be clinically significant among modern individuals when its presence increases one's fracture risk (Parfitt 1983), is the subject of much medical research. According to Garn (1982), a major concern is how to decelerate or even prevent bone loss. That is, researchers like himself "would like to know how to build a better skeleton" (Garn 1982: 14). Studies like the present one suggest that basic components of a population's adaptive strategy, such as diet, have a significant effect on the gain and loss of cortical bone. Future research in this area should continue to identify the probable effects on skeletal dynamics of dietary components, and of levels and types of physical activity. Since these are factors over which many individuals and populations have control, it may be possible to ameliorate the problem of age-related bone loss.

APPENDIX

DATA FOR ALL SPECIMENS INCLUDED IN STUDY

APPENDIX TABLE 1.--Black Earth Archaic Data: Males.

Burial Number	Categorical Age	Ranked Age	BMI (g/cm^2)	CT (cm)	Femur Length (cm)	Circ. (cm)
25	3	28	.620	.44	45.7	8.4
29	7	--	.467	.43	----	10.5
33	2	19	.552	.38	44.2	8.3
35	1	11	.548	.50	46.8	9.0
38	3	27	.523	.45	44.2	9.0
39	1	11	.697	.62	42.4	8.2
45	4	33	.544	.42	45.5	9.3
48	3	--	.583	.49	42.9	8.4
49	5	--	.441	.42	43.7	9.3
50	3	--	.588	.48	47.4	8.8
51	6	--	.639	.50	----	8.4
65	5	41	.542	.42	----	9.2
66	1	11	.643	.55	43.0	7.3
72	3	--	.679	.62	44.7	8.5
84	2	17	.664	.61	41.9	7.9
86	1	13	.579	.50	45.6	8.1
91	5	42	.689	.52	43.4	8.9
92B	6	--	.602	.50	46.8	9.1
93	5	--	.595	.49	45.0	8.5
95	4	--	.659	.56	43.8	8.3
104	6	--	.511	.42	43.2	8.3
105	3	--	.708	.62	46.5	8.6
110	2	19	.730	.64	43.0	8.7
113	2	19	.609	.53	44.4	8.1
114	1	12	.630	.46	44.0	8.1
121	5	45	.722	.64	43.3	8.7
124	4	33	.496	.37	----	8.0
130	3	24	.553	.37	44.1	7.8
133	1	08	.657	.52	42.4	7.5
137	5	--	.542	.47	45.0	9.9
138	2	--	.559	.46	43.3	8.7
140	4	37	.655	.55	----	9.1
141A	2	20	.935	.72	45.6	8.8
142	3	31	.640	.49	43.6	9.4
143	5	44	.565	.39	45.0	8.5
156	5	44	.480	.36	49.2	9.6
176	3	29	.602	.57	41.8	8.5
182	4	37	.662	.53	43.0	8.5
191	4	40	.618	.47	47.0	9.5
194	6	--	.545	.42	45.6	8.7
196C	4	34	.508	.46	42.5	8.5

APPENDIX TABLE 2.--Black Earth Archaic Data: Females.

Burial Number	Categorical Age	Ranked Age	BMI (g/cm^2)	CT (cm)	Femur Length (cm)	Circ. (cm)
1	3	26	.592	.46	43.2	7.6
4	5	--	.369	.27	42.7	7.8
7	5	--	.493	.40	40.9	7.9
17	6	--	.335	.25	----	8.2
19A	1	09	.496	.38	42.9	8.0
83	1	08	.629	.51	39.0	6.9
85	7	--	.398	.40	42.6	6.9
99	2	20	.499	.44	42.2	7.3
103	6	--	.361	.35	44.5	7.7
106	4	35	.481	.39	41.2	7.0
109	1	10	.460	.36	----	7.1
111	1	09	.457	.41	44.1	7.7
145	4	38	.482	.33	41.4	7.9
146	4	--	.609	.48	42.5	6.9
164	5	43	.417	.33	----	7.4
175A	5	46	.432	.32	----	7.8
178	3	21	.635	.43	40.8	6.6
183	4	39	.512	.37	40.3	7.7
185	3	--	.437	.34	43.5	7.7
186	4	32	.461	.37	43.0	7.6
187	6	--	.518	.37	42.2	7.7
188A	4	36	.488	.34	40.4	7.7
188B	3	30	.434	.33	41.1	7.3
193	6	--	.358	.24	----	7.4
196A	6	--	.237	.22	----	6.7
196B	3	--	.499	.38	----	6.8
200	5	47	.330	.22	----	7.2
201	2	16	.493	.37	42.6	8.2
207	4	--	.429	.31	41.4	6.9
224	2	--	.410	.29	----	7.5
225A	1	05	.589	.54	43.4	7.1
225C	7	--	.508	.39	43.6	7.5

APPENDIX TABLE 3.--Black Earth Woodland Data: Males.

Burial Number	Categorical Age	Ranked Age	BMI (g/cm^2)	CT (cm)	Femur Length (cm)	Circ. (cm)
56	3	--	.609	.50	46.1	8.1
58	1	11	.557	.58	42.0	7.3
112	3	25	.707	.51	----	8.0
169	2	14	.729	.69	40.5	8.5
170	6	--	.573	.41	----	7.5
204B	7	--	.459	.42	----	9.0
214	3	22	.695	.55	45.5	8.8
226	7	--	.654	.48	46.1	8.4

APPENDIX TABLE 4.--Black Earth Woodland Data: Females.

Burial Number	Categorical Age	Ranked Age	BMI (g/cm^2)	CT (cm)	Femur Length (cm)	Circ. (cm)
10	1	12	.476	.31	39.2	7.4
59	7	--	.542	.48	----	7.0
73	2	20	.515	.32	----	7.7
76	1	04	.575	.52	----	7.7
150	2	18	.428	.35	41.5	8.3
151	7	--	.497	.40	----	8.2
159A	7	--	.516	.43	----	8.4
190	1	06	.612	.46	40.7	7.0
195	5	--	.320	.27	----	7.2
218	1	--	.501	.36	41.3	7.4
220	1	01	.557	.41	43.5	7.0

APPENDIX TABLE 5.--Dickson Mounds, Larson Phase Data: Males.

Burial Number	Categorical Age	Ranked Age	BMI (g/cm^2)	CT (cm)	Femur Length (cm)	Circ. (cm)
334	4	05	.534	.51	----	9.5
335	5	06	.414	.43	43.0	8.2
340	3	03	.573	.57	47.4	8.8
361	1	01	.437	.43	45.3	9.5
374	3	04	.534	.49	----	8.6
380	2	02	.579	.59	----	8.5
382	5	07	.356	.42	----	8.6
396	2	02	.659	.62	48.0	10.1
399	3	04	.393	.39	44.6	8.7
413	5	07	.418	.42	44.4	9.7
415	4	05	.502	.53	42.5	8.9
432	3	04	.644	.57	42.8	8.8
451	5	06	.439	.39	47.5	9.2
473	5	06	.524	.53	44.8	9.2
475	5	06	.459	.45	44.0	8.5
482	3	04	.520	.52	44.9	9.8
485	3	04	.423	.36	45.6	9.0
487	4	05	.544	.52	----	8.4
500	2	02	.380	.52	----	10.1
508	5	06	.337	.56	47.8	9.8
566	4	05	.685	.63	43.8	9.1
578	1	01	.555	.51	----	8.1
592	7	--	.516	.50	----	10.0
636	5	06	.322	.33	46.4	9.0
649	7	--	.261	.29	----	9.2
655	7	--	.443	.35	----	9.2
664	7	--	.556	.53	44.2	9.5
669	5	06	.452	.60	----	9.8
688	5	06	.406	.35	----	10.4
864	7	--	.472	.48	----	9.6
891	7	--	.545	.59	----	9.6
913	1	01	.465	.44	41.8	8.8
1000	2	02	.542	.59	45.3	9.4
1003	3	03	.438	.41	44.7	9.2

APPENDIX TABLE 6.--Fletcher Site Data: Females.

Burial Number	Categorical Age	Ranked Age	BMI (gm/c^2)	CT (cm)	Femur Length (cm)	Circ. (cm)
002	7	--	.395	.39	42.5	8.1
011	7	--	.316	.39	40.5	8.9
012	7	--	.420	.39	----	7.7
013	1	02	.371	.32	----	7.5
026	3	08	.397	.35	----	6.4
045	1	03	.378	.29	40.0	7.8
046	5	13	.355	.39	----	8.4
054	4	12	.345	.33	----	8.9
056	2	05	.308	.33	----	7.8
061	5	--	.192	.25	42.4	9.0
088	2	07	.226	.28	----	9.7
094	3	09	.398	.36	38.9	8.3
101	1	01	.432	.34	----	7.6
103	5	14	.294	.34	----	7.7

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